Methane emissions and nitrogen excretion rates for New Zealand goats

MAF Technical Paper No: 2012/13

Report prepared for Ministry of Agriculture and Forestry
By NIWA
June 2011

Author: Lassey K

ISSN 2230-2794 (online)
ISBN 978-0-478-38820-6 (online)

April 2012

Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

BIOSECURITY NEW ZEALAND

NEW ZEALAND FOOD SAFETY AUTHORITY

Publisher
Ministry of Agriculture and Forestry
PO Box 2526
Pastoral House, 25 The Terrace
Wellington 6140
www.maf.govt.nz

Telephone: 0800 008 333

Facsimile: +64 4 894 0300

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Authors/Contributors:
Keith R. Lassey

For any information regarding this report please contact:

Keith Lassey
Principal Scientist
Atmospheric Emissions
+64-4-386 0583
k.lassey@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
301 Evans Bay Parade, Greta Point
Wellington 6021
Private Bag 14901, Kilbirnie
Wellington 6241
New Zealand

Phone +64-4-386 0300
Fax +64-4-386 0574

NIWA Client Report No:	WLG2011-19
Report date:	June 2011
NIWA Project:	MAF11302

Contents

Reviewed by

Approved for release by

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Formatting approved by

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Executive summary

A paucity of data on NZ goat husbandry has limited the ability to derive reliable estimates for enteric methane (CH_4) emission factors and nitrogen (N) excretion rates for the national goat herd. While on the one hand the small size of the goat sector compared with other livestock sectors in NZ means that such estimates need have only limited precision (for example, goat emissions are believed to account for less than 0.1% of all livestock emissions in NZ), the estimates that are adopted should nevertheless be transparently documented and justified. This report is intended to fulfil that need.

Various literature sources, including successive IPCC Guidelines, are consulted to scope estimates of emission factors (EF) and excretion rates (Nex). In addition, the NZ inventory model for sheep can be applied on the basis that sheep and goats have similar digestive systems (ruminants) and sizes. These are superimposed on plausible variations of a population scenario that recognises the diversity of goats within a herd and their population dynamics.

As expected based on comparisons of dairy and non-dairy cows, the dairy-goat sub-sector plays an important role due to the energy intensity of lactation. The relative size of that sub-sector is poorly known, though is believed to have grown over the past two decades in a context of a large decline in total goat population from 1.0 million in 1990 to 82,000 in 2009 (ie, dairy goat population may have been held fairly constant).

This report recommends values for the herd-mean EF and Nex values suitable for recent years. These values could be applied retrospectively for annual emissions from ca 1990 in the absence of quantitative information on the evolving demographics of NZ goats. Or, given the apparent decline in the proportion of dairy does during that time, lower estimates can be applied to ca 1990, and values deduced for intermediate years based on assumptions such as a near-constant dairy-doe population in a declining population of farmed goats.

Specifically, this report recommends:

1. That the herd-mean EF for the contemporary national NZ goat herd be taken as 8.5 ± 0.7 kgCH4/goat/yr. A value more representative of ca 1990 would be ~7.4 kgCH4/goat/yr. For comparison, recent inventory compilations have adopted 9 kgCH4/goat/yr for all years.

2. That the herd-mean Nex value for the contemporary national NZ goat herd be taken as 12.1 ± 1.0 kgN/goat/yr. A value more representative of ca 1990 would be ~10.6 kgN/goat/yr. For comparison, recent inventory compilations have adopted 9.5 kgN/goat/yr for all years.

3. That the methane emission specifically attributable to goat-milk production (averaging 720 kg/doe/yr with 11% milk solid by weight) be taken as 66 gCH4 per kg of milk solids. Uncertainty in this estimate is undetermined.

4. That the N excretion specifically attributable to goat-milk production be taken as 93 gN per kg of milk solids. Uncertainty in this estimate is undetermined.

All expressions of uncertainty should be taken to define a 95% confidence interval.

1 Introduction

New Zealand enteric methane (CH4) emission inventories (ie, inventories of annual CH4 emissions estimated to have been generated through enteric fermentation and emitted to the atmosphere by NZ's farmed ruminant livestock), incorporate a tiny component (~0.1%) from farmed goats. These animals are far less studied than the much more numerous sheep and cattle, and even deer. Moreover, goat emissions will have fallen dramatically over recent years due to falling farmed goat numbers from about 1 million in 1990 to about 80,000 in 2009. Because of their tiny contribution to the inventory, there has been no call for great accuracy in estimating goat emissions.

The nitrogen (N) content of goat excreta, like the excreta of other livestock. supplies N to the pasture soils that lead in part to emissions of nitrous oxide (N2O) as a result of nitrification and/or denitrification processes. Just as with enteric CH4, the goat-sourced N is sufficiently small in the context of NZ agriculture not to warrant attention to highly-accurate estimation.

Whilst farmed goats are small contributors to NZ's agricultural greenhouse gas (GHG) inventory, their estimation methodology has changed over two decades of inventory estimation and is poorly documented, contrary to agreed rules for inventory compilation. This report recommends and documents a defensible methodology.

An important determinant of feed intake, and thence of output of both CH4 and N, is the animal's live-weight (LW). In practice actual representative LWs of NZ goats are poorly known. The NZ national inventory supposes that a mean goat LW in all years matches that of a mean 1990 sheep, 40.7 kg. For the purposes of this report, MAF proposed reference goat LWs based on Hobson (2008) of 30 kg for wethers, 38 kg for does, 55 kg for bucks.

I now introduce approaches that are used to calculate the enteric CH4 inventory and N excretion levels of NZ's farmed goats.

1.1 Estimating enteric CH_4 inventory

Estimates of 'enteric methane' emissions from ruminant animals proceed through estimates of emission per head per year, known as 'emission factors' (EFs). Such EFs will of course vary strongly with animal category and depend in particular upon animal size and productivity. As a first approximation, EFs can be taken as an invariant property of a particular animal category and LW. This is the basis of tabulated IPCC 'Tier 1' EFs (IPCC 2006, Table 10.10) which report 5 kgCH4/hd/yr for a 40 kg goat.

However, invariant EFs may not correctly account for growing animals (rate of growth, proportion of feed from suckling) and do not accommodate enhancements in productivity such as in milk productivity by dairy cows or in lambing percentage by ewes. For the major animal categories in the NZ inventory (sheep, dairy, beef) such considerations are accommodated by calculating emissions from first principles using an 'energy requirements model' and deducing 'implied' EFs (IEFs) that change over time. For minor animal categories whose emissions contribute minimally to the inventory (they are not a 'key source category') and/or whose productivity variations are poorly quantified, an invariant Tier 1 EF is quite adequate. Such is the case for goats in NZ whose annual CH4 emissions are assessed in recent inventories as less than 0.08% of all enteric emissions. Thus, for NZ goats, an invariant EF is likely to prove adequate unless populations or productivity change markedly.

A particular choice of goat EF does require justification, especially if that choice differs from the IPCC default value of 5 kg(CH_4)/hd/yr (IPCC 2006, Table 10.10). In historical emission inventories reported by NZ to the IPCC/UNFCCC, a NZ-specific choice of EF for goats has been applied (see Section 2.1), but this choice has lacked clear documentation. This report provides recommendations for such a choice along with supporting documentation.

The standard first-principles approach to estimating CH_4 emission is to deploy an 'energy requirements model'. In such a model the energy expended by a representative animal in order to maintain body condition and produce as observed (eg, produce the amount of milk, or fleece, or work (bullock power), or offspring, or weight gain that is measured) is matched by the dietary intake, taking account of the efficiency with which gross dietary energy (GE) is metabolised (metabolisable energy, ME) and utilised (net energy, NE). For many animal categories and many feeds, these efficiencies are well documented. The gross energy intake (GEI) by the representative animal over a full year can thereby be assessed, a proportion of which is assumed to be diverted as CH_4 loss. This proportion, known as 'methane yield' or 'methane conversion ratio' (MCR) is generally confined to a small range, especially for pasture diets, of about 5–8%. An energy requirements model is also the basis of IPCC's Tier 1 EFs: representative livestock and feed characteristics are assembled (sometimes 'guesstimated') for a particular country of region, and an EF deduced using an energy requirements model and postulated MCR (eg, IPCC 2006, Annex 10A.1).

1.2 Estimating nitrogen excretion rates

Estimates of N excretion rate (Nex) are necessary for estimating N deposition rates onto pastures (or, in some largely non-NZ contexts, into manure managements systems), and thence enable the estimation of N2O production rates from pasture soils that result from nitrification and denitrification processes.

Estimating Nex proceeds through one of two routes. Either it is postulated exogenously based on literature values or upon IPCC Tier 1 defaults (themselves adjudged from literature values), or it is estimated on the basis of feed intakes, N content of feed, and N retention and utilisation within the animal's body. With NZ's protein-rich pastures, most (>90%) of the dietary N is excreted, and about two thirds of that via urine.

2 Reported values for goat EF and Nex

A literature search has uncovered several estimates of EF and Nex for goats (Section 2.2). But first, in Section 2.1, I examine those estimates that were reported in successive NZ National Inventory Reports (NIRs).

2.1 Prior NZ emission inventories

As with other Annex I countries, NZ submits a detailed National Inventory Report (NIR) every April to the UNFCCC. Each NIR (except in early years) includes a sequence of tabulated emission inventories in "Common Reporting Format" (CRF) in Excel files: one CRF file for 1990, one for the nominal calendar year ending 16 months earlier, and one for every year in between. For example, the NIR submitted in April 2011 includes inventory compilations for every year from 1990 to 2009, each in prescribed CRF. Each annual inventory other than the most recent reassesses previous inventories in order to assure a consistent time series in the event of reappraised activity data or a changed methodology.

2.1.1 Enteric methane emission factors

Inspection of prior NZ NIRs reveals the following for the Tier 1 enteric CH4 EF for NZ goats. For NIRs prepared up until 2002, all inventory compilations used an EF of 16.5 kg(CH4)/hd/yr. The NIR prepared in 2003 used 8.9 kg(CH4)/hd/yr. NIRs prepared from 2004 through 2011 used 9.0 kg(CH4)/hd/yr. Note that for comparison the IPCC default EF is 5 kg(CH4)/hd/yr for a 40 kg goat (IPCC 2006, Table 10.10).

The origin of the post-2002 choices of goat EF is described briefly in CRF reports. Documentation with the 2006 (and perhaps other) CRF tables describe the EF value of 9.0 kg/hd/yr as follows: *assumed to be the same per head [for all years] as the average sheep in 1990 (i.e. total sheep emissions/total NE sheep number). The goat value was not indexed to sheep over time because there is no evidence to support the kind of productivity increases that have been seen in sheep.*

Based on the CRFs prepared each year for the 1990 inventory, the goat EF of 9 kg/hd/yr appears to be the sheep IEF rounded to 1 significant figure. For example, the sheep IEF for 1990 was assessed in 2006 as 8.96 kg/hd/yr and in 2011 as 9.28 kg/hd/yr. Documentation with the 2003-compiled inventory for 1990 is ambiguous: *Horses and swine use IPCC default emission factors. Other emission factors are implied*. In the 2003 NIR both the sheep and goat EFs for 1990 are cited as 8.9 kg/hd/yr (ie, 1 decimal place). Thus it appears that the equality of 'goat EF' to 'sheep IEF in 1990' commenced literally in 2003 and perpetuated thereafter in rounded form.

Equating 'goat EF' to 'sheep IEF in 1990' implicitly presumes that the structure of the NZ goat population mirrors that of sheep which is largely oriented around the meat trade. Thus, goat LWs would match those of their sheep counterparts in 1990 which, according to the 2011 NIR, had mean LW of 40.7 kg. Emissions by lambs that are born and slaughtered within the Jul–Jun year are allocated to the sheep flock of mainly ewes alive at 30 June, so that the IEF for sheep is 'inflated' by emissions from lambs no longer alive (see Section 3.1). Thus the goat EF analogously presumes a dominance of does that are equally productive in kids, milk and fleece as ewes are in lambs, milk and fleece and with similar annual patterns of kid and lamb slaughter. As dairy goats appear to be much more prominent in the current goat population (though not necessarily in the larger goat population of ca 1990) than milking ewes are in the sheep population, the two population demographies are likely to differ markedly, casting doubt on the emission-equivalence of goat with the 1990 sheep.

What is the origin of the pre-2003 EF of 16.5 kg(CH_4)/hd/yr? This value seems, with hindsight, to be much too large.

As reported by Clark et al. (2003), the value 16.5 kg(CH_4)/hd/yr appears to originate in the very first attempt to quantify the NZ enteric inventory. Ulyatt et al. (1991) reported assessments of the CH_4 emission during 1990–91 (Jul–Jun), segregated by livestock (dairy, beef, sheep, deer, goat) and by season, and aggregated over 4 regions. These assessments were subsequently presented at a RSNZ conference and published (in shortened form) in the proceedings (Ulyatt et al. 1992). Ulyatt et al. reported a farmed goat population of 1,062,900 for 30 June 1990, plus 587,000 feral goats (and chamois). Total goat emissions for the year to 30 June 1991 were assessed at 17.5 Gg (Ulyatt et al. 1991, Table2; Ulyatt et al. 1992, Table 3). It was, however, unclear whether emissions by feral goats were included this total. Without inclusion of feral animals, the uncited IEF would then be 17.5/1.063 = 16.5 kg/hd/yr. If feral goats had been included, the IEF would then be 17.5/(1.063+0.587) = 10.6 kg/hd/yr.

The EF of 16.5 kg/goat/yr adopted in pre-2003 NIRs is therefore consistent with assuming that the estimate by Ulyatt et al. (1991) of total goat emissions excluded feral goats.

An analogous interpretation applies to deer emissions, where the EFs implied from Ulyatt et al. estimate of 29.9 Gg total deer emission could be 30.6 or 24.4 kg/hd/yr according to whether feral deer (and thar) were excluded or included from that total. Pre-2003 NIRs adopted an EF of 30.6 kg(CH_4)/deer/yr; thereafter, Tier 2 methods were apparently applied.

This author has enquired of Dr Ulyatt if he can recollect whether feral animals were included in the total estimated emission. Dr Ulyatt, who retired from AgResearch in 2000, points out that this was 20 years ago in the early days of these calculations when the inclusion in emission inventories of introduced feral animals was under debate, but adds: “However I am sure that feral goats and deer were included in the original calculation and chamois as well. We would not have mentioned them in the documentation if they were not included.”

2.1.2 Nitrogen excretion rates

Inspection of the same NIRs reveals that all inventories have adopted a value for N_{ex} of 9.5 kgN/goat/yr. According to footnotes in the corresponding CRF tables, the origin of this datum is “Ulyatt (personal communication)”. Dr Ulyatt confirms that this was little more than a ‘back-of-envelope’ estimate intended as interim.

2.2 Estimates from a literature survey

An experienced NIWA librarian undertook a search of literature databases. A search on “Goat* AND (methane AND emission*)” on each of five databases turned up 34 references, 29 of which were from the Web of Science. A similar search on “goat* AND ("dietary nitrogen" OR "dietary n")” turned up 22 references, 14 of which were from the Web of Science. Only a single reference was common to the two sub-datasets, though several of those among the 34 “CH_4 references” also reported N excretion rates (separately via faeces and urine).

Of the 55 references, several were considered not useful on the basis of their abstracts (eg, research methodology, choices of diet, experimental goals) or length (some were consistent with being abstracts only). Several other references did not withstand scrutiny. Those that revealed relevant data are summarised below and in Section 0. The Tier 1 default value proposed in successive IPCC guidelines is also included. The references are sorted chronologically by publication year except that papers by the same lead author are grouped.

Most of the references cited below report daily CH4 emissions or N excretions from a single measurement campaign. While it is possible to ‘annualise’ these emissions by simply multiplying daily emissions by 365, the uncertainty introduced this way is substantial, taking no account of seasonal variations nor of feeding circumstances outside of the experimental period. In the absence of productivity and population data such ‘annualised’ values are applicable only to animals of that particular LW, productivity and feeding regime, and should be taken only as indicative with uncertain application elsewhere.

Crutzen et al. (1986)

This paper was arguably the first to credibly assess the global enteric emission of CH_4. For each animal category or sub-category within a management regime or region, Cruzen et al. estimated or cited the GEI of a representative animal, and applied a CH_4 yield appropriate to the management regime in that category.

For goats, Crutzen et al. used Indian data (India has the largest population of domesticated goats), citing Pandey (1981) for a GEI estimate of 14 MJ/goat/d. To this GEI they applied a CH_4 yield of (apparently) 6%, to propose a CH_4 EF of 5 kg/goat/yr.

However, while Pandey (1981) tabulated DMI estimates by month for different livestock classes populating an Indian sanctuary, the conversion to GEI appears to have been a Crutzen et al. undertaking. Neither Pandey (1981) nor Crutzen et al. cited a goat LW, though Pandey assessed that 4.3 adult goats ate the same feed as a standard cow (whose LW was also not cited). If a standard Indian cow weighs a lowly 125 kg (IPCC 2006, Table A10.2) and feed consumption is proportional to $LW^{0.75}$, then for a cow to be equivalent to 4.3 goats, each Indian goat would have LW = 18 kg, which is consistent with Singhal et al.(2005) below.

This pioneering goat EF value, like several others reported by Crutzen et al. (1986) for non-bovine, non-ovine livestock, has been adopted as a default both for IPCC guidelines and for estimates of global enteric emissions (eg, Lerner et al., 1988; Johnson and Ward, 1996).

Domingue et al. (1991)

This was a NZ study focussing on N metabolism, employing 7 Angora × NZ feral goats with LW = 42.5±4.83 kg, and also employing sheep and red deer. While the experimental site was not mentioned, the authors were based at Massey University and DSIR Grasslands, suggesting a Palmerston North venue. Salient points for goats are:

- Fed lucerne hay, ad libitum
- Faecal excretion ($mgN/kgLW^{0.75}/d$): 573 (summer), 490 (winter)
- Urinary excretion ($mgN/kgLW^{0.75}/d$): 956 (summer), 888 (winter)
- Neither excretion rate was markedly different from deer, sheep
- Total excretion ($mgN/kgLW^{0.75}/d$): 1529 (summer), 1378 (winter)

For a 42.5 kg goat, total excretion (gN/d) was therefore 25.45 (summer) and 22.94 (winter) with mean 24.19. In the absence of information on seasonal variation, the scaled (annualised) excretion rate N_{ex} for a 42.5 kg goat would be 8.83 kgN/yr.

Islam et al. (2000)

This is one of several papers by the same (or similar) authorship, who were based at Tsukuba, Japan. They report an experiment deploying 8 adult male Japanese goats, mean LW 25.9 kg, divided into Groups A and B with mean LW 26.8 and 24.9 kg respectively. CH_4 emissions were measured using open-circuit respiration chambers.

Two diets are compared. Diet 1 is 85% IRG (Italian ryegrass) pellets and 15% soybean meal. Diet 2 was 50% of Diet 1 and 50% corn. Two intake levels were also compared: low (0.90×M) and high (1.60×M). Pelleted diets have different digestion characteristics from fresh pasture. High intake levels would seem the better proxy for grazing conditions.

Salient CH_4 results were (‘SE’ refers to standard error in the difference):

- CH_4 yield is 5.31%, 7.00% on Diets 1, 2 (averaged over intake levels): SE=0.25%, $p<0.01$
- CH_4 yield is 5.93%, 6.39% on high, low intakes (averaged over diets): SE=0.16%, not significant ($p>0.05$)
- CH_4 emitted, 10.6, 11.5 g/d on Diets 1, 2 (averaged over intake levels): SE=0.56 g/d, not significant ($p>0.05$)
- CH_4 emitted, 13.6, 8.5 g/d on high, low intakes (averaged over diets): SE=0.59 g/d, $p<0.001$

Because the 4 values (Diets 1 & 2 averaged over intakes, low & high intakes averaged over diet) are not independent (sum of 1st pair = sum of 2nd pair), one cannot isolate values for Diet

1, high intake that offers the best proxy for NZ grazing conditions. The best available proxy is high intake, averaged over diets, for which the annualised CH_4 yield is 5.93%, and EF is 4.96 $kgCH_4/hd/yr$

Salient results for daily N excretion (gN/d) were:

- Via faeces: 4.6, 3.6 on Diets 1, 2 (averaged over intake levels): SE=0.30, not significant ($p>0.05$)
- Via urine: 8.0, 4.7 on Diets 1, 2 (averaged over intake levels): SE=0.36, $p<0.0001$
- Thus total N_{ex}, via urine+faeces: 12.6, 8.3 on Diets 1, 2.
- Via faeces: 5.6, 2.7 on high, low intakes (averaged over diets): SE=0.36, $p<0.0001$
- Via urine: 7.1, 5.6 on high, low intakes (averaged over diets): SE=0.16, $p<0.0001$
- Thus, total N_{ex}, via urine+faeces: 12.7, 8.3 on high, low intakes.

For high intake, averaged over diets, the annualised N_{ex} is 4.6 kgN/hd/yr.

Islam et al. (2001)

This paper seems to follow up Islam et al. (2000), possibly even with the same 8 castrated male Japanese goats (mean LW = 34 kg). This is a comparison of feeds, all of which are additives to IRG (Italian ryegrass) silage, chopped but not pelleted. I report here only for the control diet, which is the IRG silage without additives. CH_4 emissions are measured with open-circuit respiration chambers.

For CH_4 emission:

- CH_4 yield = 5.54%
- CH_4 emission rate = 37.09 g/d/100kg(LW), which equates to 12.6 g/d and annualises to an EF of 4.60 $kgCH_4/hd/yr$

For N excretions:

- Via faeces, urine: 0.27, 0.44, summing to 0.71 $gN/d/kg(LW)^{0.75}$
- For LW = 34 kg, total N excretion rate is 9.99 gN/d, annualised to 3.6(5) kgN/yr.

Islam et al. (2002)

This short paper reports an experiment with 4 male Japanese goats (LW + 26 kg), comparing emissions when fed pelleted and 'conventional' feeds at three intake levels (1.0M, 1.5M, 2.0M). Diets were not pasture-related, comprising mainly dried sugarcane tops (50%), soybean meal (15%), rice bran (10%), molasses (10%). Goats consumed the allotted diets except that some of the roughage portion of conventional feed was refused at the 2.0M level. Islam et al. reported CH_4 yields in the range 6–7%, slightly higher in pellet feeding ($P < 0.05$), but N losses were slightly higher (not significant) for conventional feeds.

Vermorel (1997)

The author is based in Saint-Genès-Champonelle, which is near Clermont-Ferrand, west of Lyon in France. The text is fully in French, but with title and abstract translated into English.

According to the abstract, the paper estimates enteric CH_4 from sheep and goats in France using energy requirement models and 1994 population data, together with CH_4 production determined using respiration chambers. The following is taken from that abstract. "Mean yearly methane emissions of a suckling ewe (16.7 m^3) or a dairy ewe (17.8 m^3) are close to that of a dairy goat (22.9 m^3). Methane emission of a ewe lamb is similar to that of a young goat (8 m^3/yr)." Note that 1 m^3 of methane at STP has mass 0.714 kg, so that these CH_4 volumes translate to EFs of 11.9 kg/yr (suckling ewe), 12.7 kg/yr (dairy ewe), 16.4 kg/yr (dairy goat) and 6 kg/yr (young goat). According to the text, a suckling ewe has average mass 60kg. The dairy ewe has mass 70kg and produces 270 litre milk. The dairy goat has mass 60kg and produces 600 litre milk. There does not seem to be a category of non-lactating adult female goat, but a buck of mass 100 kg emits 24.6 m^3 CH_4/yr (17.6 kg/yr) and an average kid (25 kg at 5 months, 45 kg at 1 yr) emits 8.6 m^3 CH_4/yr (6.1 kg/yr).

Vermorel et al. (2008)

This paper (in French, but with title and abstract translated into English) assesses the French enteric CH_4 inventory for 2007 using Tier 3 methodology. The abstract quotes enteric CH_4 EFs for dairy and suckling ewes of 14.4 and 11 kg/hd, and 14.3 kg/hd for goats in 2007.

In their Table 3, Vermorel et al. disaggregate the goats into the following categories with respective EFs (kgCH_4/hd for 2007): dairy goats (14.3), young goats (5.0), bucks (13.5), other goats (9.1), with weighted mean EF 11.9 kg/hd. Thus it appears that the EF attributed to 'goats' in the English abstract in fact referred to the subset of dairy goats (LW = 65 kg; milk productivity 650 kg/yr including fat production of 35 kg/yr (ie, 5.4% fat)).

Singhal et al. (2005)

This paper seeks to estimate the total Indian enteric CH_4 inventory using a 'dry matter intake approach' together with literature values for CH_4 yield that are based on indigenous breeds and indigenous feeds. Goats are described as follows. Adults (1–2 yr) have LW in the range 12–27 kg, and 70% of the juvenile goats (<1 yr old, but 30% are considered not to emit CH_4 due to a 'non-functioning rumen', presumably due to a milk diet) have LW in the range 8.8–22 kg. The adult and juvenile goats have a DMI of 3.0–4.0 and 3.0 kg/100kg(LW). The MCFs of lactating goats are in the range 18–29 gCH_4/kgDMI. From such data, Singhal et al. estimate EFs averaged among different categories of livestock. For male goats these EFs (kgCH_4/hd/yr) are 2.83 (juvenile) and 4.23 (adult). For females they are 2.92 (juvenile), 4.99 (adult, milking), 4.93 (dry).

It is unclear how applicable these might be to NZ grazing conditions with their very different feeds and LW.

Puchala et al. (2005)

This study, at Langston University (OK, USA), examined the effect of feeds containing condensed tannin on Angora does. I consider only the control cases in which the feed was an approximately equal mix of crabgrass (*Digitaria ischaemum*) and Kentucky tall fescue (*Festuca arundinacea*) with DM digestibility 51%. CH_4 emissions were determined using a 'four-animal head box open-circuit respiration calorimetry system'. Twelve Angora does (LW = 40 kg) emitted 10.6 gCH_4/hd/d (average over 6 measurement days), or 16.2 gCH_4/kgDMI. Neither the GEI nor the GE content of feed seems to be reported. Annualising the daily CH_4 emission suggests an EF of 3.9 kgCH_4/goat/yr.

Animut et al. (2008)

This is the fourth of 4 papers dealing with the effects of condensed tannins in goat feed on CH_4 emissions. Conducted at Langston University (OK, USA), CH_4 emissions are measured using open-circuit calorimetry system with 4 head boxes, as also used by Puchala et al.

(2005). I consider only the control diet of sorghum-sudangrass (*Sorghum bicolour*) with only 0.3g condensed tannin per kg DM.

The experiment used 24 yearling Boer × Spanish wethers (7/8 Boer; initial LW 34.1±1.02 kg). The goats, approximately 18 months old, were fed at 1.3 × maintenance. According to their Table 4, the mean CH_4 emission rate was 26.2 l/d (18.7 g/d) or 8.77% of GEI (seems high!). The 18.7 gCH_4/d scales up to an annualised EF of 6.8 kg/hd/yr.

In terms of N metabolism, Animut et al. report per-animal intake of 11.1 gN/d, of which 3.84 and 6.17 gN/d were excreted in faeces and urine respectively. The total excretion rate of 10.0 gN/hd/d annualises to 3.65 kgN/hd/yr.

Bhatta et al. (2008)

Four adult (2 yr-old) Japanese goats with mean LW 26±5.4 kg were fed a succession of 19 different diets comprising various mixtures of Timothy hay, alfalfa hay, maize, soybean meal, concentrate and additives. I will focus on diets without concentrates and additives of which there are two: D_1 (the control diet) is 70% Timothy hay, 20% maize, 10% soybean meal (by weight); D_9 is 100% alfalfa hay. Bhatta et al. report the lowest emission levels when alfalfa was a major part of the diet, with D_9 leading to the lowest emission of all 19 diets.

Bhatta et al. did not report daily CH_4 emissions, instead reporting emissions as a proportion of different measures of intake (DMI, DDMI, DOMI, GEI). The MCRs reported for D_1 and D_9 were 7.8% and 5.1%.

Herrero et al. (2008)

This paper provides a comprehensive but broad-brush analysis of ruminant emissions throughout all of Africa. It categorises agro-ecosystems and animal distributions and uses a model that relates feed quality to enteric CH_4 production. The ruminants include cattle, goats and sheep, but all reported tabulations of numbers (by agro-ecosystem and region) lump these together into TLUs (tropical livestock units); 1 TLU is defined as 250 kg LW. Herrero et al. deduce ‘emission factors’ (kgCH_4/TLU/yr) in the range 21–40 with mean of 31, which matches the IPCC default Tier 1 EF for cattle (31 kg/hd/yr). The latter estimate is associated with African cattle with LW in the range 200–275 kg (depending on sub-category). Unfortunately, Herrero et al. do not report indicative LWs for goats (or sheep). Nonetheless, a goat of LW 25 kg, being 0.10×TLU, would thus correspond to an EF of ~3 kgCH_4/goat/yr.

IPCC Guidelines (eg, IPCC 1996; 2000; 2006)

IPCC Guidelines — from 1994, revised in 1996, Good Practice Guidance in 2000, and most recently in 2006 — have all tabulated Tier 1 EFs for enteric CH_4 inventories for all common livestock classes. For bovines, regionally-dependent EFs acknowledged regional variation in breeds (and therefore LWs), in productivity and in management. Tier 2 methodologies for bovines were also included and refined in successive Guidelines. A Tier 2 methodology for sheep was offered in the Good Practice Guidance of 2000 and in the 2006 Guidelines. For all other livestock classes only Tier 1 ‘default’ values were offered.

The author of this report was a participating expert in the Good Practice Guidance (IPCC 2000, Chapters 4.1 and 4.2, ‘Livestock Population Characterisation and CH_4 Emissions from Enteric Fermentation in Domestic Livestock’), and an author of the 2006 Guidelines (IPCC 2006, Chapter 10, ‘Emissions from Livestock and Manure Management’). Furthermore, the author was responsible, with assistance from Dr Marc Ulyatt, in formulating and introducing into the IPCC guidelines a Tier 2 methodology for characterising sheep borrowed strongly from the energy requirement recommendations of the UK Agricultural and Food Research Council (AFRC 1993).

In the case of goats, the Tier 1 EF in all Guidelines was 5 kgCH_4/hd/yr (IPCC 1996, Table 4-3; IPCC 2006, Table 10.10), citing Crutzen et al. (1986) (above) as the datum source.

The 2006 Guidelines offered improved guidance on how to assess Tier 1 EFs for unrepresented livestock categories. The guidelines recommended "to use the Tier 1 emission factors for an animal with similar digestive system and to scale the emission factor using the ratio of the weights of the animals raised to the 0.75 power. Liveweight values have been included [in the tabulation] for this purpose" (IPCC 2006, footnote to Table 10.10). It was then necessary to accompany Tier 1 EFs with corresponding LWs, which for goats was unreported by Crutzen et al. (1986). IPCC authors adjudged a goat LW of 40 kg to be appropriate. Thus, the sources of the EF of 5 kgCH_4/goat/yr (Crutzen et al. 1986) and of the LW of 40 kg (IPCC 2006, Table 10.10) are disconnected. With the EF based on Indian data, Indian goats would likely have LW less than 40 kg (eg, see Singhal et al. (2005) above).

Note that the concept that feed demand at maintenance scales with $LW^{0.75}$ is well established; $LW^{0.75}$ is often termed 'metabolic weight' (MW).

IPCC Guidelines appear to have first reported N_{ex} for goats in 2006 (IPCC 2006, Table 10.19). The multi-various data sources make tracing individual entries problematic. That tabulation reports the daily N excretion rate per 1000kgLW rather than per head. For goats, a value 0.45 kgN/1000kgLW/d is reported for North America, and much higher values in the range 1.28–1.42 kgN/1000kgLW/d for all other regions, with the largest value, 1.42 kgN/1000kgLW/d, for Oceania. These values are systematically higher than corresponding values for sheep. Furthermore, for all regions except Latin America, Africa and the Middle East, goats (followed by sheep) have the largest reported N excretion rates per unit LW of any animal, from poultry to cattle. For those three named regions, N excretions only from swine are larger (and more than twice the value for swine in any other region). Such a disparity in estimates seems surprising. The Oceania value of value 0.45 kgN/1000kgLW/d scales to an annualised N_{ex} value for a 38 kg goat of 20 kgN/hd/yr. This rather large value may further test the credibility of Table 10.19 in IPCC (2006) and suggest that some numbers lack a 'reality check'. Were the N excretion rate associated with North America to be used instead, the annualised N_{ex} would be 6.2 kgN/hd/yr, a value which may suggest that the N_{ex} value attributed to North America is better founded.

2.3 Summary of pertinent reported EF and Nex values

From the data sources in Sections 2.1 and 2.2 can be selected those with credibility in a NZ context. Such selections, appropriately rounded, are assembled in Table 1. Most entries in this table are not immediately transferrable to population means as they are based on short-term measurements for specific animals and specific feeds.

Table 1: Summary of pertinent goat methane emission factors and nitrogen excretion rates from literature sources.

LW (kg/goat)	EF ($kgCH_4$/goat/yr)	N_{ex} (kgN/goat/yr)	Data origin	Source
40.7	9	9.5	NZ	Recent NZ inventories
	5		India	Crutzen et al. 1986)
42.5		8.8	NZ	Domingue et al. (1991)
25.9	5.0	4.6	Japan	Islam et al. (2000)
34	4.6	3.6	Japan	Islam et al. (2001)
60	11.9		France	Vermorel (1997)
70 (dairy)	12.7		France	Vermorel (1997)
65 (dairy)	14.3		France	Vermorel et al. (2008)
9–22	4.2–5.0		India	Singhal et al. (2005)
40	3.9		OK, USA	Puchala et al. (2005)
34.1	6.8		OK, USA	Animut et al. (2008)
25(?)	3		Africa	Herrero et al. (2008)
40(?)	5	21	Oceania	IPCC (2006)

3 Emission factor estimates for methane based on energy requirement models

This chapter estimates goat EFs for enteric CH_4 emissions using several methodologies developed for application to sheep. With sheep globally more numerous than goats and their husbandry being economically important in several countries, including NZ, more effort has been expended in developing detailed methodologies. This section applies such sheep methodologies to goats, recognising their similar digestive systems body sizes, even if feeding behaviours differ: goats are predominantly browsers whereas sheep are grazers.

3.1 IPCC Tier 1 methodology

If the IPCC (2006) Tier 1 value for sheep is uncritically taken as better founded than the counterpart for goats, then one can check their consistency using the scaling rules according to metabolic weight, $LW^{0.75}$, (see Section 2.2, “IPCC Guidelines”). The Tier 1 EF of 8 kgCH_4/sheep/yr with corresponding LW = 65 kg (IPCC 2006, Table 10.10) appears adequate to describe NZ adult sheep (even if the LW may be too heavy). Scaling by $(38/65)^{0.75}$ suggests an adult goat EF of 5.3 kg CH_4/goat/yr, which is consistent with the IPCC Tier 1 EF of 5 kg CH_4/goat/yr (Table 1) for goats of unspecified productivity.

Note that the IPCC Tier 1 EF for sheep differs markedly from the IEF in the NZ inventory — eg, 11.2 kg CH_4/sheep/yr for 2009 reported in the 2011 NIR. This is because the latter is calculated as the quotient of the total annual emission from all sheep categories divided by the population as at 30 June in the assessed year, and thereby allocates the emissions of all lambs that are born and slaughtered within the Jul–Jun year to the population alive at 30 June. Because most sheep counted at 30 June are ewes, the IEF effectively allocates to the ewe both her emissions and those of her lambs. There is no guarantee that such an IEF is well founded for application to the goat population.

3.2 Tier 1 estimate based on NZ methodology for sheep

Instead of scaling the IPCC default EF for sheep (Section 3.1), one can instead scale the NZ-specific sheep IEF. The sheep IEF for 1990 in the 2011 NIR is 9.3 kg CH_4/sheep/yr. As noted in Section 3.1, this sheep IEF allocates emissions from the entire sheep flock to those alive on 30 June 2009 when their average LW is estimated at 40.7 kg. The corresponding scaled IEF for goats of $(38/40.7)^{0.75} \times 9.3 = 8.8$ kgCH_4/goat/yr therefore also allocates annual emissions from the NZ goat herd to those alive on 30 June on the basis of a similar demographic profile to that of NZ sheep.

The above calculation differs from the goat EF reported in recent NZ NIRs only by adopting a ‘reference’ goat weight of 38 kg, rather than matching the weight of a 1990 sheep, 40.7 kg, which results in the goat IEF also matching that of the 1990 sheep. The two input values for goat LW are sufficiently similar that the respective EFs do not differ when rounded to 1 significant figure, viz, 9 kgCH_4/goat/yr.

If the above calculation were instead related to the more productive NZ sheep of 2009 with IEF = 11.2 kg CH_4/sheep/yr and LW = 48.4 kg, the scaled EF for goats would be $(38/48.4)^{0.75} \times 11.2 = 9.3$ kgCH_4/goat/yr, which is still unchanged when rounded to 1 significant figure.

Thus, all of these scaled estimates of goat EF are consistent with 9 kgCH_4/goat/yr, a value that assumes a similar age profile to that of sheep, including the population bulge following kidding and lambing followed by slaughters before the year end, and that allocates emissions from those animals slaughtered to those counted on 30 June. Thus if there is indeed a spring-time bulge in goat population and that it is proportionately smaller than that in sheep, then the scaled EF of 9 kgCH_4/goat/yr would prove too large. Conversely, if the proportion of does that produce commercial quantities of milk (dairy does) far exceeds the proportion of dairy ewes, then the scaled EF should be enlarged accordingly.

3.3 IPCC Tier 2 methodology for sheep

The IPCC Tier 2 methodology for sheep (IPCC 2006, Section 10.2), which is based on AFRC (1993) methodology, can in principle be applied to NZ goats, allowing for the relatively minor differences between their characteristics. In practice, this application is limited by the data paucity for NZ goats and their demographics. As noted in Section 1, MAF have supplied ‘reference LWs’ for NZ goats of 30 kg (wethers), 38 kg (does), and 55 kg (bucks).

I have therefore prepared a model to apply the methodology. Cast in an Excel® spreadsheet, this model can be made available on request.

3.3.1 Disaggregating the population

I have somewhat arbitrarily disaggregated NZ’s goats into 6 sub-categories whose emissions can potentially differ markedly, even if individual population characteristics are poorly established. Those sub-categories and their defining characteristics are as follows:

- Dairy does: LW of 38 kg, reared predominantly for milk production, averaging 720 kg(milk)/doe/yr and producing 1 kid/doe/yr
- Breeding does: LW of 38 kg, reared predominantly for breeding kids (1 kid/doe/yr) for either the meat trade or the fibre trade
- Dry does: identical to dairy or breeding does, but which neither gestate not lactate
- Bucks: LW of 55 kg
- Other adults (eg, wethers, yearlings): LW growing from 30 kg to 38 kg through the year, with mean LW 34 kg, or 32kg for those culled during the year
- Kids: one kid per doe born in mid-September, reared and weaned after 20 weeks when their LW is 17.4 kg, followed by 18 weeks on pasture feed (or 9 weeks for those culled), growing to 30 kg by 30 June

The above purely indicative characteristics are approximately consistent with, but not necessarily fully supported by, statistics on the NZ goat herd (Hobson 2008). Such statistics suggest a kidding percentage of 93% which is here approximated to 1 kid per doe. Breeding from yearling does is ignored (and in any event, in my population scenario below the yearling would have been reclassified as a breeding or dairy doe by the time of kidding). Only ‘other adults’ and kids are presumed to gain weight. The kid LW at weaning is based on lamb husbandry as a multiple of birth-weight (see below for more detail), even though goats are older at weaning than lambs. The weaning weight is also consistent with a constant rate of weight gain of ~0.7 kg/week from birth through to a LW of 30 kg at 30 June.

3.3.2 Standard population scenario

The methodology is superimposed on a ‘population scenario’ of the above sub-categories in the contemporary NZ goat herd, constructed to assure a stable population with seasonal variation (even though a ‘stable population’ has not been a reality over the past 20 years). The population scenario is simplistic and little more than guesstimated, being only weakly constrained by available NZ statistics (Hobson 2008). However, imposing such a scenario is necessary in order that the population demography be sustained (ie, to ensure that deaths match births). My ‘standard population scenario’ is expressed through a ‘representative herd’ based on 1000 dairy does, structured as follows:

- At the year start (1 Jul) every 1000 dairy does are matched by 1000 breeding meat or fibre does, by 40 bucks (ie, one buck per 50 does: Hobson (2008)), and by 800 ‘other adults’ (mainly wethers and yearlings). Thus the ‘representative herd’ comprises 2840 goats. The 50:50 mix of dairy:non-dairy does is ‘guesstimated’, but is compatible with recent statistics. For example, 51,000 dairy goats were registered in NZ in 2002 (Rare Breeds Conservation Society, 2005) out of a population reported for 2002 in the 2011 NIR of 153,000. The proportion of dairy goats is believed to be rising (H. Clark, personal communication) in a falling NZ goat population that currently numbers 82,230 (for 2009 in the 2011 NIR), so the 50:50 mix seems adequate for recent years.
- Each of the 2000 does bear and raise to weaning one kid. Of those kids 60% are culled between weaning and 30 June, leaving 800 to be re-categorised next 1 July to ‘other adults’. Although this implies a kidding percentage of 100%, unproductive does can be envisaged as embedded among ‘other adults’. Alternatively, the number of culls can be adjusted to leave 40 surviving kids per 100 breeding/dairy does.
- 400 does (20% of the 2000) are culled between weaning their kids and end of year.
- 400 (50%) of the ‘other adults’ are culled during the year, and the other 400 are re-categorised on the following 1 July to replace the culled breeding and dairy does.
- Thus, the representative herd of 2840 alive at 1 July gain through births and lose through deaths to re-attain 2840 again by 30 June, comprising 1600 does, 40 bucks, 400 other adults, and 800 kids; the following day (1 July), the last two categories are re-categorised as 400 does and 800 other adults. The composition of the herd one year earlier is thus reinstated.
- ‘Dry does’ are considered only for the purpose of examining the role of gestation and lactation on CH_4 emission and N excretion (a requirement of this report). Thus, while they are excluded from the population mix, they are assumed to have the same cull rate as dairy does to enable direct comparison between those two sub-categories.

Incorporation of a population scenario is not a requirement of this report. It affects the estimated emissions in each sub-category only in as far as it determines the proportion of animals in each sub-category that are culled and therefore neither emit CH_4 nor excrete N for the entire year to 30 June. Thus the number of deaths matches the number of births. Note that it also accounts for a bulge in goat numbers following kidding until some of those kids (and ‘other adults’) are slaughtered (as per lambs and hogget sheep). The IEFs for individual sub-categories except kids are the total emission by that sub-category of goat per live head at the year’s commencement (ie, at 1 July), allowing for intra-year culls. The use of ‘IEF’ in place of ‘EF’ emphasises this point. The IEF ascribed to kids is the combined emission from all kids born and reared expressed per kid reared, only 40% of whom survive to 30 June. The population scenario enables a herd-average IEF to be estimated (ie, the total CH_4 emission by goats throughout the year per goat alive at 1 July).

A similar calculation to the above estimates N excretion rates within and across sub-categories, supplemented by estimates of N excreted by milk-fed kids, which emit no CH_4.

In Section 5.3 I examine variations in the above ‘standard’ population scenario in order to gauge uncertainty (and variability) in the herd-mean IEF and N_{ex}.

3.3.3 Model output

A summary of the model output is shown in Table 2. The following specific assumptions are inherent in the methodology of that model, which includes some data used in Section 3.4. Few of these assumptions are rigorous and default to the IPCC Tier 2 methodology for sheep.

1. As with most animals, the energy requirement of body maintenance is proportional to metabolic weight, MW. Specifically, maintenance net energy (NE) requirement is C_F×MW. AFRC (1993) recommend C_F values for ewes of 0.217 MJ/kg$^{0.75}$, for lambs of 0.236 MJ/kg$^{0.75}$, and for rams of 0.250 MJ/kg$^{0.75}$, which values are incorporated into IPCC (2006). For goats, AFRC recommend the much larger value 0.315 MJ/kg$^{0.75}$, which claims to be validated by data. This is in contradistinction with the Australian Feeding Standards (CSIRO 2007) that underlie the NZ inventory model in which maintenance energy requirements for goats match those for sheep of the same MW. There is an unconfirmed possibility that the 0.315 MJ/kg$^{0.75}$ is in fact a metabolic energy (ME) rather than NE requirement (NE is approximately 0.79×ME). In view of this we adopt the maintenance NE requirement appropriate for sheep, adopting the ewe, ram and lamb values for does, bucks and kids, respectively.
2. All goat sub-categories are raised on what AFRC (1993) refer to as ‘lowland pasture’, implying daily walking of up to 3000 m horizontally and 100 m vertically, and standing for 12 hours (post-weaning in the case of kids).
3. Kids are weaned at 17.4 kg, calculated as 5.5 times their birth-weight of 3.16 kg (0.2065 × maternal MW in kg$^{0.75}$). These values are representative of sheep (AFRC 1993) and their applicability for goats with their longer weaning period is unconfirmed. Nonetheless, it is consistent with a constant growth rate of 0.70 kg/week from birth through weaning to 30 kg at 30 June.
4. Milk produced by breeding does to rear a kid to weaning is 166 kg (taken from Section 3.4). This production is significantly higher than for ewes with suckling lamb which has default value of 5 times the weight gain of the lamb from birth to weaning (AFRC 1993; IPCC 2006). If applied to does raising kids from 3.16 to 17.4 kg this default milk production would be only 71 kg(milk)/yr. The higher milk production reflects the longer duration that kids are milk fed.
5. Milk production by dairy goats averages 720 kg/yr (taken from Section 3.4).
6. The NE value per kg of milk production is 2.835 MJ(NE)/kg, quoted by AFRC (1993) as suitable for ‘Saanen/Toggenburg’ does. This value is less than the default value for ewe’s milk, 4.6 MJ/kg based on 7% butterfat, consistently with a lower butterfat of about 3% in NZ goat’s milk (see Section 3.4). Doe’s milk better resembles cow’s milk than ewe’s milk, and a ‘middle-of-the road’ composition of 3% butterfat and 3.2% protein is assumed (CSIRO 2007; Rare Breeds Conservation Society, 2005).
7. The fleece of all goats except bucks is clipped for the fibre trade. Per-animal production is taken to be 8% (unscoured weight) of LW per year. Thus a 38 kg doe would average 2.9 kg of fleece annually, which is similar to the weight per clip for fibre goats from MAF data (Section 3.4). The NE value of unscoured fleece is 24 MJ/kg. These data are appropriate for sheep (AFRC 1993), with unconfirmed applicability to goats reared for their fibre production. It may also be inappropriate to apply the 8% value to meat goats (see Section 3.4), though the proportion of these is poorly determined. However, the energy required for fleece production is generally small so little error would be incurred.

8. The only sub-categories assumed to require energy for growth are ‘other adults’ (from 30 to 38 kg for unculled, 30 to 34 kg for culled animals) and kids (from 17 to 30 kg post-weaning). No allowance is made for a lesser weight gain by kids culled before the year end. The algorithm for growth is as for juvenile sheep (IPCC 2006, Eqn 10.7).
9. All pasture feed has GE content of 18.45 MJ/kgDM, and an energy digestibility of 71%, characteristic of NZ pastures that goats might be expected to browse and comparable to the seasonally averaged DM digestibility of 71.4% used in the NZ inventory model for sheep pasture (A. Pickering, personal communication).
10. For all goats except kids, 6.5% of the GEI is emitted as enteric CH_4, while 4.5% of GEI by kids is so emitted. These proportions are recommended by IPCC (2006, Table 10.13) for sheep and for lambs (up to 1 yr of age).

Note that as an estimate of the NZ enteric CH_4 inventory for goats, Table 2 merely supplies an indicative scenario, depending as it does on the ‘standard’ population scenario for NZ goats as well as upon the assumptions enumerated above. Variations in the standard scenario are discussed in Section 5.3.

Table 2 highlights the fact that each of the average GEI, DMI and IEF, expressed per goat alive at 1 July, can be higher than most or even all of their counterparts for corresponding sub-categories. That arises because at 1 Jul the populations are at their lowest, being prior to kidding. Thus, the CH_4 is emitted by far more animals than are present on 1 July due to the ‘kid bulge’ in population. An analogous feature arises in the sheep IEF due to the lamb bulge. The population-mean IEF of Table 2 is surprisingly close to that of the 1990 sheep on which recent NZ inventories have been based (9 $kgCH_4$/hd/yr).

Table 2 also reveals the range in IEFs among sub-categories, and in particular it exposes the importance of the dairy doe category (not surprisingly, in view of the elevated EF for the dairy cow counterpart). Individual IEFs for all adult non-dairy sub-categories are comparable to the IPCC Tier 1 value of 5 kg/goat/yr (Table 1).

Table 2: Nominal enteric CH_4 inventory for NZ goats based on an indicative sub-categorisation to which the IPCC (2006) Tier 2 methodology based on sheep is applied.

Goat sub-category	Population scenario[a]	Body-weight (kg)	Estimated GEI (MJ/hd/yr)	Estimated DMI (kg/hd/yr)	Methane IEF ($kgCH_4$/hd/yr)	Inventory scenario ($GgCH_4$/yr)
Dairy does	35.2→28.2%	38	9727	527	11.36	0.33
Breeding does	35.2→28.2%	38	5565	302	6.50	0.19
Dry does	0%	38	4070	221	4.75	
Bucks	1.4%	55	5886	319	6.87	0.01
Other adults	28.2→14.1%	30→38	3434	186	4.01	0.09
Kids (weaned)	0→28.2%	17→30	2161	117	1.75	0.10
Total/Average[b]	82,230 hd		7956	431	8.75	0.72

[a] Scenario of population change throughout the year (nominally 1 Jul through to 30 Jun) due to maturation and culls; animals are re-categorised on 1 Jul to reinstate a stable population. The total head count of 82,230 is the NZ goat population reported in the 2011 NIR for 2009.

[b] Average GEI, DMI and IEF are expressed per head as at 1 Jul except for kids which are expressed per kid born and raised.

Part of the brief of this report was to estimate the CH_4 emission and N excretion associated with goat-milk production. This has application in estimating the emission cost inherent in the NZ Emissions Trading Scheme (ETS). This is estimated here by estimating the emissions and excretions of a dairy doe in excess of those of a dry doe. The latter, absent from the population scenario, shares the population structure of the former, and so has identical energy requirements apart from the requirements of gestation and lactation. Effectively, the CH_4 emission per unit of kg milk relates to the energy value of milk production plus a share of the energy cost of gestation.

From the IEFs in Table 2 for dairy does and dry does, the former produces 6.6 kg more CH_4 per year (2.4× as much). That extra 6.6 $kgCH_4$/yr is therefore associated with a production of 720 kg milk. At a milk-solid (MS) composition of 11% (kg/kg) (Hobson 2008), this corresponds to a CH_4 emission cost of 83 gCH_4 per kg(MS).

3.4 Tier 2 methodology using the NZ inventory model

The Australian feeding standards (eg, CSIRO 2007) have been adapted to the NZ ruminant grazing situation (cattle, sheep, deer only) to form the basis of the NZ Tier 2 inventory model (Clark 2008). As an alternative methodology to the IPCC Tier 2 methodology of Section 0, the former is deemed the more appropriate for NZ’s grazing circumstances. The NZ model includes monthly time steps to account for intra-annual variations in population and changes in categorisations. This author is unfamiliar with the detail of the NZ inventory model and does not have access to the software. Consequently, all data for this section is kindly supplied and documented by MAF (A. Pickering, personal communication), and reproduced here, largely verbatim or near-verbatim, with permission.

The premise is that the NZ inventory model for sheep can be applied to goats, adjusting parameters where necessary and where supported by appropriate data (eg, Hobson, 2008), including running the model with various assumptions about milk productivity. The model parameters that were adjusted are as follows:

- The standard reference weights: these are set to 30 kg (wethers), 38 kg (does), 55 kg (bucks). The growth rate of bucks is set to zero, whereas in the sheep model rams are presumed to grow at 50 g/d (=18 kg/yr).
- The expression for energy requirement for milk production: this is adjusted to match the CSIRO equation for goats of 0.0492 × mf + 1.309 MJ(NE)/kg, where 'mf' denotes milk fat content in g/kg. For a milk fat content of 3% or 30 g/kg (eg, AFRC 1993; CSIRO 2007) this energy requirement equates to 2.785 MJ(NE)/kg which agrees very closely with the 2.835 MJ(NE)/kg attributed by AFRC (1993) to 'Saanen/Toggenburg' does and adopted in Section 3.3.3.
- Lactation distribution: this is based on a kidding date of 24 September and weaning date of 15 February, the lactation distribution by month is set as follows:
  - for non-dairy does, 10% in each of September and February, 20% in each of the intervening months, October to January
  - for dairy goats, 10% in each month, September to June

The following variables were input to the model (taken largely from Hobson (2008)):

- Slaughter weight of doe = 13.5 kg.
- Kid carcass weight = 9.5 kg.
- Greasy fleece weight = 1.2 kg/goat/yr. This is based on clips of 2 kg per fibre-goat wether, 2.6 kg per fibre-goat doe, and 2.3 kg per fibre-goat yearling (Hobson 2008). It is assumed that meat goats do not produce very much fibre and therefore to account for meat and fibre goats the fibre-goat value was halved. Currently, data on fibre and meat goat proportions of the national flock have not been found. A more robust assumption could be made if this information was available.
- Dairy doe milk yield = 700 l/doe/yr = 720 kg/doe/yr (2.3 kg/doe/d over a 305-day lactation period).
- Non-dairy doe milk yield = 161 l/doe/yr = 166 kg/doe/yr. The sheep model dictates that ewes produce 100 litres per year, which, with a 90-day lactation period, corresponds to 1.1 l/doe/d fed to the suckling lamb. While a meat or fibre goat will produce less milk daily than a dairy goat, it seems reasonable to suppose that her daily milk yield might be similar to that of a ewe, but over a longer (145 day) lactation period. Milk butterfat is taken as 3%.
- The N content in body fat and fleece is the same as for sheep.
- Dressing out percentages: taken as 48% (kids) and 35% (does)
- Population model: category populations are arbitrary (and immaterial when output is expressed per head) but intra-year variations are as for the corresponding sheep category consistent with a stable population in each sub-category across years and with a kidding percentage of 93%.

Table 3 presents the model output as supplied by MAF, including also N_{ex} estimates.

Also shown in Table 3 is the result of imposing the standard population scenario of Section 3.3.2 on the MAF-sourced data to produce herd-average DMI, IEF and N_{ex}. Thus in effect, the sheep model for intra-annual population dynamics is put into a context in which the goat sub-categories are re-categorised according to the scenario of Section 3.3.2. The following mappings of the sub-categories in Table 3 onto those in the population scenario reported in Table 2 are as follows:

- ‘Other adults’ in Table 2 are identified with 50% wethers + 50% yearlings in Table 3.
- ‘Yearling breeders’ in Table 3 are not directly represented in Table 2 and therefore unweighted in the population average; they are considered to be subsumed into ‘breeding does’ of Table 2 as their kids would be born when the yearling has been so re-categorised.
- The two kid sub-categories in Table 3, which are combined into the ‘kids’ sub-category of Table 2, require further explanation. In the model for sheep, lambs are presumed born at 1 Sep, weaned after 3 months, and slaughtered lambs meet their fate at 6 months of age (nominally 1 March). In those 6 months lambs are subjected to natural mortality of 2% per month. The entry ‘kids (birth–Mar)’ in Table 3 covers the kid analogue of those lambs. Surviving lambs are re-categorised as hoggets from 1 March, and their analogue to 30 Jun is denoted ‘kids (Apr–Jun)’ in Table 3. The lamb/hogget scheme does not realistically transfer to goats, which are weaned at 5 months. The standard goat population scenario of Section 3.3.2 and Table 2 assumes a 60% cull rate of kids halfway between weaning and 30 June. In adapting the ‘lambs’ and ‘hogget’ category in the NZ inventory model to the goat population scenario of Section 3.3.2, I have mapped the ‘lamb’ category to ‘kids (birth–Mar)’ and the ‘hogget’ category within the same year to ‘kids (Apr–Jun)’, and weighted the latter in the population according to the number of kids that are not culled (40% in the standard scenario). This mapping is clearly imperfect, but is considered adequate.

From the EFs in Table 3 for dairy does and dry does, the former produces 5.2 kg more CH_4 per year (2.2× as much). Since only the requirements of gestation and lactation differ, that extra 5.2 kgCH_4/yr is associated with a production of 720 kg milk which includes 79 kg of MS (11%). Thus, there is a CH_4 emission cost of lactation of 66 gCH_4 per kg(MS).

4 Tier 2 methods for nitrogen excretion rate estimation

This section applies some of the Tier 2 methods that were used for enteric CH_4 EFs in Chapter 3 to estimate N excretion rates, N_{ex}. Tier 2 methods for N cycling (intakes, utilisation, retention and excretion) through the ruminant animal are less well developed than counterparts for energy cycling that leads to CH_4 excretion rates. Tier 1 estimates of N_{ex} from the literature are summarised in Table 1. The following subsections address N_{ex} as deduced wholly or partly from Tier 2 data both in the IPCC Guidelines and in the NZ inventory model.

Table 3: Enteric CH4 emissions and N excretion rates for NZ goats in various categories as estimated by the NZ Tier 2 inventory model for sheep. These estimates and goat sub-categories are supplied by MAF (A. Pickering, personal communication).

Goat sub-category	Body weight (kg)	Estimated DMI (kg/hd/yr)	Methane IEF ($kgCH_4$/hd/yr)	N excretion rate (kgN/hd/yr)
Dairy does	38	461	9.6	13.6
Breeding does	38	305	6.37	9.0
Dry does, Wethers	38	209	4.38	6.2
Yearling breeders[a]	30	281	5.30	7.8
Yearlings	30	279	5.28	7.5
Bucks	55	352	7.35	10.4
Kids (birth–Mar)		98	1.65	2.4
Kids (Apr–Jun)		61	1.03	1.7
Population average[b]		425	8.46	12.1

[a] Yearling breeders refer to does that get pregnant in their second year while still a yearling.

[b] Average GEI, DMI and IEF are obtained by applying the population scenario of Section 3.3.2 as described in the text, and expressed per head as at 1 Jul except for kids which are expressed per kid born and raised.

4.1 IPCC Tier 2 methodology

Section 10.5.2 of IPCC (2006) discusses ways of combining information on N intakes (other than milk) and N retention to deduce estimates of N excretion. The N intake can be deduced as the product of dietary intake (DMI), and N content (mass fraction of DM) of that diet. The dietary N content can be related to the crude protein (CP) content through the conversion factor 6.25 kgCP/kgN (IPCC 2006, Eqn (10.32)). For kids an allowance for milk-sourced N and N retained in growing body tissues should be added.

The NZ inventory model generally assumes a universal 3% N content in pasture diet (A. Pickering, personal communication), so that N intakes by goat sub-categories are just 3% of the DMI estimates in Table 2. To this should be added N intake by milk-fed kids. This is estimated on the basis of: milk-protein content of 3.1% (31 g/kg) and 6.38 kg milk protein per kg N (eg, see IPCC (2006, Eqn 10.33) for cow's milk, which goat's milk closely resembles and for which protein content can be estimated as 19+0.4×mf g/kg, with mf denoting milk-fat content in g/kg). The N level in body tissue is taken as 2.6% by mass (NZ inventory model). Thus a milk intake to weaning of 166 kg/kid includes a N intake of 0.81 kgN/kid of which 0.37 kgN/kid is retained and 0.44 kgN/kid excreted.

Thus, the mean per-goat intake, excluding milk, of about 431 kgDM/yr (Table 2) corresponds to a mean N intake of 12.9 kgN/goat/yr which is augmented to 13.5 kgN/goat/yr by N in kids' milk diet. This estimate is of course a function of the goat population scenario in Table 2.

If approximately 10% of pasture-N intake is retained by the goat (IPCC 2006, Table 10.20), then the N excretion rate N_{ex} will be 2.7% of dietary DMI (except milk) or 11.6 kgN/goat/yr (IPCC 2006, Eqn 10.31) which is augmented to 12.0 kgN/goat/yr to allow for kids' milk diet. However, this 'ball-park' estimate of 10% retention is non-specific, and may not fully represent NZ pastures and dairy goat productivity (because the higher protein intake during lactation may not balance the protein level in the milk). Thus, while a value for N_{ex} of 12.0 kgN/goat/yr may be satisfactory for a herd average, it may be inappropriate in particular for lactating goats, and for this reason, a full column of N_{ex} is omitted from Table 2 (which in any case would just be a scaled DMI, apart from kids). This also means that a N-excretion cost of lactation cannot be reliably made by comparing N_{ex} for dairy and dry does.

4.2 New Zealand inventory model

Estimates of N_{ex} based on feed intakes and N retentions in the NZ inventory model based on Australian feeding standards (CSIRO 2007) are reported in Table 3. The underlying assumptions are reported in Section 3.4.

The largest 'N-excretors' are dairy does and bucks, reflecting the fact that they are also the largest eaters (high DMI).

For all but the two kid categories in Table 3 the N_{ex} values are ~2.95% of DMI, which suggests that very little of the dietary DM-N is retained. The lower values for the kid categories (2.5 and 2.8%) reflect a greater N retention in gained weight.

From the N_{ex} values in Table 3 for dairy does and dry does, the dairy doe excretes 7.4 kg more N per year (2.2× as much). Since only the requirements of gestation and lactation differ, that extra 7.4 kgN/yr is associated with a production of 720 kg milk including 79 kg of MS. Thus, there is a 'N excretion cost' to lactation of 93 gN per kg(MS).

5 Discussion and comparison of estimates

I have tabulated and contextualised various estimates of enteric CH_4 EFs and of N excretion rates that are either assessed as representative of the NZ goat population (Chapter 3) or could potentially be applied to that population or to specific disaggregations of that population (Chapter 2). Consider the CH_4 EF and the N_{ex} estimations separately, following which the uncertainties in EF and N_{ex} values are addressed.

5.1 Estimates of enteric CH4 emission factors

Differences between Tables 2 and 3 can be expected due to different assumptions about intra-year population dynamics and animal categorisations as well as the underlying methodological differences. When compared to the NZ inventory model (Table 3), the IPCC model (Table 2) yields larger IEFs for does, by 18% (dairy), 2% (breeding) and 9% (dry), whereas that same model yields smaller IEFs for the other categories, by 6% (bucks), and by 17% (both other adults and kids). This level of agreement is considered satisfactory. The IPCC model yields a herd-mean IEF that is only 3% higher.

What is more surprising is the discrepancy between the emission cost per kg of milk solid between the two models: 83 versus 66 gCH_4 per kg(MS). This cost is largely determined by the (net) energy value of milk, with a smaller energy cost of gestation spread across the annual milk production, together with the GEI required to supply that NE. One would expect all these parameters to be similar between the models as long as the milk composition (especially milk-fat content) is also similar. This discrepancy has not been explored in this study. On the basis that the NZ inventory model is likely to better encapsulate NZ grazing conditions, the latter estimate of 66 gCH_4 per kg(MS) would be favoured.

Table 4: Effect of five 'plausible' population scenarios on population-mean CH_4 emission and N excretion, as calculated by the NZ inventory model.

Population scenario	Population mean IEF ($kgCH_4$/hd/yr)	Population-mean N_{ex} (kgN/hd/yr)
Standard	8.46	12.1
Low dairy	7.89	11.3
High dairy	9.03	12.9
Low kid cull	8.14	11.6
High kid cull	8.88	12.7
Minimal dairy	7.43	10.6

5.2 Estimates of N excretion rates

The two inventory models yield near-identical herd-mean N_{ex} values: 12.0 kgN/goat/yr (Section 4.1) and 12.1 kgN/goat/yr (Section 4.2 and Table 3). While the good inter-model agreement is encouraging, the actual value would be dependent on the particular population scenario.

An estimate of ‘N excretion cost’ to lactation is available only from the NZ inventory model (Section 4.2), yielding 93 gN per kg(MS).

5.3 Estimates of uncertainties

The largest source of uncertainty in herd-mean estimates of IEF and N_{ex} is likely to stem from the uncertainty in the population mix, especially in the proportions of dairy does and of kids in the population. Accordingly, I consider variations in the ‘standard’ population scenario of Section 0, by postulating extremes in the contemporary population mix that could plausibly (but not rigorously) be associated with 95% confidence intervals. I postulate two ‘plausible’ splits between dairy and non-dairy kid-bearing does with all other sub-categories unchanged, and two ‘plausible’ variations in the cull rate of kids which have implications for the age structure of the population. Finally, I consider a ‘minimal-dairy’ scenario which might reflect the situation up to and through the mid 1990s when the goat population was an order of magnitude higher than today, but believed to be dominated by fibre and meat goats. The ‘standard scenario’ of Section 0 and its five ‘plausible’ variations are as follows.

1. ‘*standard scenario*’ (as already considered) — dairy:non-dairy does are split 50:50, so that there are 1000 (35%) of each in the ‘representative herd’ of 2840 goats, as per Table 2.
2. ‘*low-dairy scenario*’ — as per standard scenario except that dairy:non-dairy does are split 25:75, so that the representative herd of 2840 goats can be thought of as having 500 (17.5%) dairy and 1500 (52.5%) non-dairy does.
3. ‘*high-dairy scenario*’ — converse of the low-dairy scenario with 75:25 split of dairy:non-dairy does, so that the 2840-strong representative herd has 1500 (52.5%) dairy and 500 (17.5%) non-dairy does.
4. ‘*low-kid-cull scenario*’ — based on the standard scenario but the population has lower mean age due to a 40% cull rate of kids instead of 60% countered by a 30% cull rate of does (after weaning) instead of 20%. In the representative herd 1000 dairy and 1000 non-

dairy does produce 2000 kids of which 1200 survive to be categorised as ‘other adults’. Including 40 bucks, the representative herd now has 3240 goats at 1 July. To match the 2000 births, 800 (40%) kids, 600 (50%) ‘other adults’ plus 600 (30%) does are slaughtered during the year.

5. ‘*high-kid-cull scenario*’ — converse of the low-kid-cull scenario with higher mean age due to a 80% cull rate of kids and a 10% cull rate of does. Thus, only 400 kids survive to be re-categorised as ‘other adults. The representative herd at 1 July then has 2440 goats comprising 1000 dairy and 1000 non-dairy does, 400 ‘other adults’ (50% of which are slaughtered during the year) and 40 bucks.
6. ‘*minimal-dairy scenario*’ — as per low-dairy scenario except that dairy:non-dairy does are split 5:95. The representative herd of 2840 goats can then be thought of as having 100 (3.5%) dairy and 1900 (67%) non-dairy does. The dairy doe representation in the herd is just 10% of that in the standard scenario.

Table 4 reports the herd-mean IEF and N_{ex} for the six population scenarios, calculated using the NZ inventory model as per Table 3. The IEF in Table 4 for the standard scenario reproduces entries in the last row of Table 3.

Scenarios 1–3 above encompass variations in the split between dairy and non-dairy does. To the extent that this range of variation can be associated with 95% confidence in plausible splits, then the herd-mean IEF would be 8.5±0.6 $kgCH_4$/hd/yr and herd-mean N_{ex} would be 12.1±0.8 kgN/hd/yr. Likewise, scenarios 1, 4–5 encompass variations in the rates of kid culls and thence in the mean herd age. Associating these variations with a 95% confidence range suggests a herd-mean IEF of 8.5±0.4 $kgCH_4$/hd/yr and herd-mean N_{ex} of 12.1±0.6 kgN/hd/yr. All of these uncertainty ranges embrace the estimates of Table 2, suggesting that the IPCC and NZ inventory models do not yield significantly different estimates.

The two variations—that in dairy:non-dairy split and that in level of kid culls—can be taken as independent, so the combined 95% confidence limit can be deduced through ‘squaring and adding’ the confidence ranges. This suggests a EF for NZ goats of 8.5 ± 0.7 $kgCH_4$/goat/yr (viz, ±8%), and a N excretion rate N_{ex} of 12.1±1.0 kgN/goat/yr (viz, ±8%).

The minimal-dairy scenario suggests that if the much larger goat sector of the early 1990s indeed contained a proportionately much smaller dairy sub-sector (but possibly a similar number of dairy does in absolute terms), then the corresponding herd-mean IEF and N_{ex} values would have been much smaller, typically 7.4 $kgCH_4$/hd/yr and 10.6 kgN/hd/yr respectively. Both of these are outside the above 95% confidence range. This serves to highlight the higher emissions and excretions from dairy goats, much as have been reported for dairy versus non-dairy cows (eg, IPCC 2006, Table 10.11).

If one supposes that during the period 1990–2009 when the goat population fell by a factor of about 12 that the absolute number of dairy does remained approximately constant, then the herd-mean IEF and N_{ex} values would have risen from about 7.4 to 8.5 $kgCH_4$/hd/yr and 10.6 to 12.1 kgN/hd/yr respectively due solely to a growing proportion of dairy does. Values for IEF and N_{ex} for intermediate years could be interpolated according to total goat population.

The above scenario analysis provides no guidance for the uncertainty in CH_4 emission or in N-excretion by a specific goat sub-category (eg, by dairy goats). Consequently, estimates of the uncertainty in the CH_4 emission and N-excretion ‘costs’ per kg of milk solids are unavailable.

6 Recommendations

Recommendations of this report are:

1. That the herd-mean emission factor for enteric methane emission by the contemporary national NZ goat herd be taken as 8.5 ± 0.7 kgCH_4/goat/yr. This emission factor would have increased since the 1990s from ~7.4 kgCH_4/goat/yr concomitantly with the increasing proportion of dairy goats in the national herd that is believed to have taken place.
2. That the annual N excretion averaged per goat in the contemporary NZ herd be taken as 12.1 ± 1.0 kgN/goat/yr. This excretion rate would have increased since the 1990s from ~10.6 kgN/goat/yr concomitantly with the increasing proportion of dairy goats in the national herd.
3. That the methane emission associated with goat-milk production (averaging 720 kg/doe/yr with 11% milk solid by weight) be taken as 66 gCH_4 per kg of milk solids. Uncertainty in this estimate is undetermined.
4. That the N excretion associated with goat-milk production be taken as 93 gN per kg of milk solids. Uncertainty in this estimate is undetermined.

All expressions of uncertainty should be taken to define a 95% confidence interval. For detail on the origin of these estimates, see Sections 5.1 (methane emission) or 5.2 (N excretion).

7 Acknowledgements

The author is indebted to Marcus Ulyatt (AgResearch, retired) from whom he learned a lot about ruminant science, and in particular who helped construct the IPCC methodology for methane emissions by sheep. Andrea Pickering (MAF) adapted the NZ inventory model for goats, supplying both the underlying assumptions and model output (see especially Section 3.4). Harry Clark (AgResearch and the NZ Agricultural Greenhouse Gas Research Centre) provided a timely review of this report.

8 Glossary of abbreviations and terms

CH_4	methane
CP	dietary crude protein, usually expressed as a percent of DM
CRF	Common Reporting Format (for emission inventories)
CSIRO	Commonwealth (of Australia) Scientific and Industrial Research Organisation
DM	dry matter (mass of sample after oven-drying at typically 60°C)
DMI	dry matter intake (mass(DM)/time)
EF	Emission Factor (for enteric CH_4: kgCH_4/hd/yr)
ETS	NZ Emissions Trading Scheme
GE	gross energy of combustion of dried feed (MJ/hd)
GEI	gross energy intake (GE/time)
GHG	greenhouse gas
IEF	implied EF: ratio, annual emission to population (kgCH_4/hd/yr)
IPCC	Intergovernmental Panel on Climate Change
LW	live weight (also known as ‘bodyweight’) (expressed in mass units: kg)
MAF	Ministry of Agriculture and Forestry
MCR	methane conversion ratio, also known as 'methane yield'
ME	metabolisable energy: GE less that of faeces, urine and CH_4 (MJ/hd)
methane yield	enthalpy of emitted methane as a percent of GEI (or, in gCH_4/kgDM))
MS	milk solid (mass)
MW	metabolic weight, $(LW)^{0.75}$, with which maintenance energy requirements scale ($kg^{0.75}$)
N	nitrogen
N_2O	nitrous oxide
NE	net energy, as utilised by the animal: ME less that lost as heat (MJ/hd)
N_{ex}	Nitrogen excretion rate (kgN/hd/yr)

NIR	National Inventory Report
NZ	New Zealand
UNFCCC	United Nations Framework Convention on Climate Change

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