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Direct greenhouse gas emissions of the South African small stock sectors

C.J.L. du Toit[1,2#], W.A. van Niekerk[2] & H.H. Meissner[3]
[1] Department of Animal Science, Tshwane University of Technology, Private Bag X680, Pretoria, 0001, South Africa
[2] Department of Animal and Wildlife Sciences, University of Pretoria, 0002, South Africa
[3] 189 van Riebeeck Avenue, Lyttelton Manor, Centurion, 0157, South Africa

Abstract

There are increasing concerns about the impact of agriculture and livestock production on the environment. As a result, it is important to have accurate estimations of greenhouse gas (GHG) emissions if reduction measures are to be established. In this study the direct GHG emissions from South African sheep and goats during 2010 were calculated. Calculations were done per province and in total. The Intergovernmental Panel on Climate Change (IPCC) methodology, adapted for tropical production systems, was used to calculate methane (CH_4) and nitrous oxide (N_2O) emissions on a Tier 2 level. Small stock is a key methane emission source in the South African livestock sector, and is responsible for an estimated 15.6% of the total livestock emissions. Small stock contributed an estimated 207.7 Giga gram (Gg) to the total livestock methane emissions in South Africa in 2010, with sheep producing 167 Gg and goats producing 40.7 Gg. Calculated enteric methane emission factors for both commercial and communal sheep of 8.5 kg/head/year and 6.1 kg/head/year, respectively, were higher than the IPCC default value of 5 kg CH_4/head/year for developing countries. A similar tendency was found with goat emission factors. The highest sheep and goat methane emissions were reported for the Eastern Cape province, primarily because of animal numbers.

Keywords: Greenhouse gas, methane, nitrous oxide, sheep, goats

[#]Corresponding author: dutoitcjl@tut.ac.za

Introduction

Agricultural activities contribute to greenhouse gas emissions through a variety of processes (Kebreab *et al*., 2006; Alemu *et al*., 2011; Archibeque *et al*., 2012; Scholtz *et al*., 2012). According to the Department of Environmental Affairs and Tourism (DEAT), agriculture, forestry and land use (corrected for carbon sink values) emitted an estimated 4.9% of the total South African greenhouse gas (GHG) emissions in 2004, making it the third largest GHG contributor after the energy sector (79%) and industrial processes (14%). Emissions from livestock are the largest contributor (98%) to methane emissions from the agricultural sector (Otter, 2010). Blignaut *et al*. (2005) reported that livestock was responsible for 41% of the total methane emissions in South Africa. The livestock sector contributes to GHG emissions through methane (CH_4) emitted directly from animals, and methane and nitrous oxide emitted from manure management. Methane emissions by ruminants are produced in the rumen during microbial fermentation of feed, especially carbohydrates, (Sallaku *et al*., 2011). The production of methane is associated with a loss of 2% - 14% of dietary energy (Johnson & Johnson, 1995; Sallaku *et al*., 2011). Methane and nitrous oxide have higher global warming potentials than carbon dioxide. Methane is 21 to 25 times more effective in trapping heat in the atmosphere, and nitrous oxide has a global warming potential of 296 to 310 times that of CO_2 (FAO, 2006; IPCC, 2006; ANIR, 2009). This makes agriculture and livestock an attractive target for GHG reduction campaigns as small changes in agricultural emissions could result in large changes in total GHG emissions.

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Methane production in livestock is influenced by several factors, including the level of feed intake, diet composition, digestibility and quality of forage, forage species and cultivar and variation among animals (Scholtz *et al.*, 2012). Otter (2010) calculated the livestock emissions for South Africa in 2004 according to IPCC guidelines and reported livestock methane emissions as 1383 Giga grams (Gg) and nitrous oxide emissions as 11.8 Gg.

South African livestock production is based on a unique combination of commercial (intensive and extensive) and emerging and communal (subsistence) production systems. The level of productivity and efficiency between these two main production systems varies greatly in certain areas and it is important to distinguish between them when calculating GHG emissions. Sheep and goat farming is practised throughout South Africa, but is concentrated in the more arid regions such as Northern Cape and Eastern Cape provinces.

Previous inventories (Blignaut *et al.*, 2005; DEAT, 2009; Otter, 2010) were conducted on a national scale utilizing Intergovernmental Panel on Climate Change (IPCC) default values (Tier 1 approach) for some or all of their emission calculations. These emission factors do not distinguish effectively between classes of animals, production efficiencies and production systems. They are often based on assumptions of animals utilizing highly digestible diets and temperate forages (Mills *et al.*, 2001) that are not representative of South African production systems. Pelchen & Peters (1998) reviewed methane emissions from sheep, and found that estimations of the rate of methane emission from sheep vary widely among authors, which emphasises the use of country-specific emissions factors for inventory purposes.

The objective of this paper is to report the methane and nitrous oxide emissions of sheep and goat production systems in South Africa as calculated in total and per province. For that purpose a Tier 2 approach was adopted, in contrast to previous estimates, which used primarily Tier 1. Direct emissions from enteric fermentation and manure management systems are presented.

Materials and Methods

The current inventory is based on small stock population data of 2010. A Tier 2 approach has been adopted for sheep and goat emission calculations in accordance with the IPCC (2006) good practice guidelines. The methodology employed to compile the inventory was also based on the Australian national greenhouse accounts, National Inventory Report (ANIR, 2009), which contains both Australian country specific and IPCC default methodologies and emission factors. Although the Australian methodology is based on that of the IPCC, it is adapted to Australian conditions, which are more representative of South African conditions. In addition, South Africa is a country with diverse climatic and growth conditions which influence seasonal feed quality, suited animal breeds to regions and production systems. Therefore, to attempt to reduce errors associated with averaging input data across areas with large physical and managerial differences, the inventory was conducted on a provincial basis. The provincial totals were aggregated to give national totals.

Population numbers were based on figures provided by the Abstract of Agricultural Statistics (Stats South Africa, 2010), Department of Agriculture, Forestry and Fishery statistics (DAFF, 2010) and relevant industry associations (Mohair South Africa, 2010; NGWA, 2010; Boerbok South Africa, 2011; South African Milch Goat Breeders Society, 2012). These figures were cross-referenced with slaughter data, wool production and milk production data for the same period.

Sheep

The South African sheep industry consists of a well-defined commercial sector and an emerging and communal sector (subsistence farmers). The emerging and communal small stock sectors were grouped under communal production systems. Population figures in each of these two sub-sectors were downscaled to the following breed types: Merino, other wool, non-wool and karakul breeds according to population data from statistics South Africa (Stats South Africa, 2010). The flock structures used in the emission calculations were based on an average South African flock structure (NWGA, 2011). It was assumed that the commercial and emerging/communal sectors would have similar flock structures. The flock structure consisted of older breeding rams (1%), breeding ewes (45%), young breeding rams (2%), young ewes (12%), weaned lambs (16%) and lambs (23%).

Sheep liveweight per age group and breed type are reported in Appendix B.1 and B.2. The weight data were sourced from breed societies (NWGA, 2011; Afrino Breeders’ Society of South Africa, 2011; Döhne

Merino Breed Society of South Africa, 2011; Dorper sheep Breeders' Society of South Africa, 2011; Karakul Club, 2011; Merino Breeders' Society of South Africa, 2011; South African Mutton Merino breeders' Society, 2011) and compared with figures reported by Meissner *et al*. (1983). Communal animals are smaller, within a similar breed type, than commercial animals and a 20% weight reduction was assumed for emerging/communal animals compared with commercial animals across all age groups and breed types.

The natural rangeland (veld) in South Africa can be divided broadly into three main veld types in terms of grazing: sweetveld, sourveld and mixed veld. Sweetveld will remain palatable and nutritious even when mature, and can support animals throughout the year, whereas sourveld is palatable only during the growing season, and animals will typically lose weight when grazing sourveld in the dormant season. Mixed veld represents an intermediate between sweetveld and sourveld (Smith, 2006). The South African small stock industry is based predominantly on extensive grazing systems. The proportions of sweet, sour and mixed veld per province are reported in Table 1 (based on Tainton, 1999).

Table 1 Ratio of veld types per province (Tainton, 1999)

Province	Sweetveld	Sourveld	Mixed veld
Western Cape	0.5	0.3	0.2
Northern Cape	1.0	0	0
Eastern Cape	0.35	0.35	0.3
Free State	0.8	0.1	0.1
KwaZulu-Natal	0.2	0.6	0.2
Mpumalanga	0.15	0.7	0.15
Limpopo	0.6	0.2	0.2
Gauteng	0.2	0.6	0.2
North West	0.7	0.25	0.05

The quality of veld will vary according to veld type and season of use. The intake and methane production of animals will vary as the quality of veld changes through the seasons. The digestibility of veld between and within veld types and between seasons was sourced from literature (Dugmore & Du Toit, 1988; De Waal, 1990; O'Reagain & Owen-Smith, 1996) and is reported in Table 2.

Sheep and goats are selective grazers and browsers and will select for a higher quality diet. Commercial production systems employ supplemental feeding strategies that will improve the overall quality and utilization of the diet on offer. A 5% increase in the dry matter digestibility (DMD) reported in Table 2 was assumed for commercial small stock production systems to account for selective grazing and supplementation practices in the methane emissions calculations.

Table 2 Seasonal dry matter digestibilities (%) of South African veld types (Dugmore & Du Toit, 1988; De Waal, 1990; O'Reagain & Owen-Smith, 1996)

Season of use	Veld type		
	Sweetveld	Sourveld	Mixed veld
Spring	65	65	65
Summer	60	60	60
Autumn	55	50	50
Winter	50	45	45

Sheep methane emissions estimates are based on Howden & Reyenga (1987), who reported a close relationship between dry matter intake (DMI) and methane production. Howden & Reyenga (1987) based their work on analysis of Australian respiration chamber experiments with sheep and found that DMI explained 87% of the variation in methane production of sheep.

The potential intake of sheep is dependent on body size and the metabolizability (ME/GE) of the diets received by the animals (ANIR, 2009). The potential intake of sheep (PI), (kg DM/head/day) is given by AFRC (1990) as:

$PI = (104.7q_m + 0.307W – 15.0)\ W^{0.75}/1000$ …………………………………........... Equation 1

Where: W = liveweight (kg) (Appendix B.1; B.2)

q_m = metabolizability of the diet (ME/GE) = 0.00795DMD – 0.0014 (Minson & McDonald, 1987). Dry matter digestibility is expressed as a percentage (Table 2).

The average DMD of the various veld types and seasons is increased by 5% to allow for the selection of quality by sheep. Feed intake increases during lactation (ARC, 1980). It was assumed that 80% of commercial ewes and 50% of emerging/communal ewes will lamb during the year. Commercial production systems will employ two breeding seasons with 80% of the national flock lambing in autumn and 20% lambing in spring (L. Kruger, 2012, Pers. Comm., ARC-Animal Production Institute, Private bag X2, Irene, 0062, South Africa). This ratio was used for all provinces except Northern Cape, where only an autumn lambing season was assumed, and Western Cape, where a winter lambing season was assumed. It was assumed that communal production systems would lamb throughout the year (L. Kruger, 2012, Pers. Comm., ARC-Animal Production Institute, Private bag X2, Irene, 0062, South Africa). The intake of lactating animals was increased by 30% during the season in which lambing occurs (ANIR, 2009). Based on relationships presented by the SCA (1990) the additional intake for milk production (MA) was calculated as:

$MA = (LE \times FA) + ((1 – LE) \times 1)$ ………………………………………………………………. Equation 2

Where: LE = portion of breeding ewes lactating, calculated as the annual lambing rates x proportion of lambs receiving milk in each season (Appendix B.3)

FA = feed adjustment (assumed to be 1.3)

The daily methane production (M), (kg/head/day) was then calculated using intake figures generated from equation 1 based on the relationship published by Howden & Reyenga (1987):

$M = I \times 0.0188 + 0.00158$ ………………………………………………….……………. Equation 3

Goats

The goat industry consists of a meat goat sector (commercial and communal), a milk goat sector and an Angora goat sector. Flock structures were assumed to be similar to the sheep flock structures and were verified by industry organizations (Boerbok South Africa, 2011; Mohair South Africa, 2011; M. Roets, 2012, Pers. Comm. P.O. Box 461, Scientific Roets, Kokstad, 4700, South Africa). The liveweight of commercial goats was sourced from industry and experts (Boerbok South Africa, 2011; Mohair South Africa, 2011; Roets, 2004) and is reported in Appendices C.1 to C.4. The emerging/communal sector goats are assumed to be smaller and less productive than meat goats in the commercial sector and their liveweights were based on commercial goat weights less 20%, similar to sheep calculations. It was assumed that milk goats and Angora goats are only farmed with commercially. Goats that are milked in the communal sector are mainly dual purpose and have a comparative low milk yield compared with commercial dairy goats. These goats were therefore incorporated into the emerging/communal meat goat class for the purpose of this inventory.

Dietary quality parameters used in the goat emission calculations were assumed to be similar to sheep diet quality for commercial and communal goat production systems across all seasons. The enteric methane emissions calculations for all goat breed types (meat, milk and Angora) followed the same methodology as for sheep based on the ANIR (2009). The enteric methane emissions were calculated using Equations 1, 2 and 3 above. Meat goat emission calculations were split into commercial and communal goats based on the population data (DAFF, 2010; Stats South Africa, 2010). It was assumed that lactating milk goats would receive a higher quality diet with a DMD of 70% throughout the year. Two kidding seasons, autumn and spring, were assumed for commercial meat goats with 80% of does kidding during the year. Communal meat goats are bred throughout the year with 50% of does kidding during the year. The ratio of kidding seasons between the provinces was similar to the ratio used for sheep production systems. Milk goat and Angora goat producers employ only a single autumn breeding season with 95% and 70% of does kidding in milk goats and Angora goats, respectively (Muller, 2005). The lactation feed adjustment was taken as 1.3 during the season of kidding and 1.1 during the season after kidding for milk goats.

Manure management

Manure methane

South African small stock production systems are mainly extensive, and manure is deposited directly onto pastures and veld/rangeland with no active manure management occurring. Methane emissions from manure (M), (kg/head/day) of all categories of sheep and goats were calculated as:

$M = I \times (1 - DMD) \times MEF$ …………………………………………………..………… Equation 6

Where: I = intake as calculated under enteric emissions

MEF = emissions factor (kg CH_4/kg DM manure). The factor of 1.4×10^{-5} based on the work of Gonzalez-Avalos & Ruiz-Suarez (2001) was used.

The loss of animals owing to predators and stock theft is one of the major challenges for South African small stock producers. Some producers overnight sheep and goats in enclosures where manure deposition will be concentrated and be managed in a drylot or compost system. Accurate data on the number of animals that overnight in enclosures are not available, and although this is noted, it is not incorporated into the inventory.

Nitrous oxide

Because sheep and goat production systems in South Africa are mainly extensive, the amount of nitrous oxide emitted from manure deposited on rangelands is minimal. Nitrogen in faecal matter is primarily organic and must first be mineralized before it becomes a source of N_2O. This process occurs at significant rates in regions with high rainfall. However, in dryer regions, decomposition of faeces is much slower, with faeces remaining largely intact for months to years (ANIR, 2009). Nitrous oxide emissions originating from faecal matter deposited directly on veld or pastures are not reported in this paper as these emissions are not recorded under livestock emissions, according to the IPCC (2006) good practice guidelines, but under the managed agricultural soils section in the national inventory report format.

Results and Discussion

In 2010, direct methane emissions from South African livestock were estimated at 1328 Gg (Du Toit *et al*., 2012). The small stock industry produced an estimated 207.7 Gg of methane in the same year, with sheep producing 167 Gg and goats producing 40.7 Gg. The total small stock figure is higher than emissions calculated for 2004 of 167 Gg (Otter, 2010), despite a decrease in total population size from 2004 to 2010. The 2004 inventory was conducted on a Tier 1 level, utilizing IPCC (2000) default values for both sheep and goats. The present inventory was compiled on a Tier 2 level with emission factors calculated from country-specific data.

Sheep

The South African sheep population in 2010 was estimated to be 24.6 million with 65% of the national flock consisting of Merino and other wool-type breeds (DAFF, 2010; Stats South Africa, 2010). Commercial sheep are responsible for 90.6% of the total sheep emissions of 167 Gg, with emerging/communal sheep contributing 9.4%. Approximately 86% of the sheep are concentrated in the Eastern Cape, Northern Cape, Free State and Western Cape provinces. Merino sheep are the greatest contributors to sheep methane emissions, followed by non-wool breeds, other wool breeds and Karakul sheep with 81.7 Gg (49%), 48.3 Gg (29%), 36.5 Gg (21.9%) and 0.17 Gg (0.1%), respectively.

Table 3 Estimated methane emission factors for South African commercial sheep

Animal class	**Merino**			**Other Wool**			**Non Wool**			**Karakul**		
	Weight (kg)	**$\text{MEF}_{\text{enteric}}$ (kg/h/year)**	**$\text{MEF}_{\text{manure}}$ (kg/h/year)**	**Weight (kg)**	**$\text{MEF}_{\text{enteric}}$ (kg/h/year)**	**$\text{MEF}_{\text{manure}}$ (kg/h/year)**	**Weight (kg)**	**$\text{MEF}_{\text{enteric}}$ (kg/h/year)**	**$\text{MEF}_{\text{manure}}$ (kg/h/year)**	**Weight (kg)**	**$\text{MEF}_{\text{enteric}}$ (kg/h/year)**	**$\text{MEF}_{\text{manure}}$ (kg/h/year)**
Breeding rams	97.5	14.7	0.0042	138.0	22.2	0.0064	97.5	14.7	0.0041	72.5	10.5	0.003
Breeding ewes	53.0	8.07	0.0022	68.0	10.4	0.0029	63.5	9.66	0.0027	48.0	7.28	0.002
Young rams	78.3	11.5	0.0032	98.3	14.8	0.0042	68.3	9.88	0.0027	53.0	7.64	0.002
Young ewes	42.5	6.21	0.0016	55.5	8.01	0.0022	47.5	6.88	0.0018	40.5	5.94	0.0016
Weaners	37.5	5.54	0.0014	31.5	4.77	0.0012	37.5	5.54	0.0014	33.5	5.02	0.0013
Lambs	22.5	3.62	0.001	22.5	3.62	0.001	22.5	3.62	0.001	22.5	3.62	0.001

MEF: methane emissions factor; kg/h/year: kg/head/year.

Table 4 Estimated methane emission factors for South African communal sheep

	Merino			**Other Wool**			**Non Wool**			**Karakul**		
Animal class	**Weight (kg)**	**$MEF_{enteric}$ (kg/h/year)**	**MEF_{manure} (kg/h/year)**	**Weight (kg)**	**$MEF_{enteric}$ (kg/h/year)**	**MEF_{manure} (kg/h/year)**	**Weight (kg)**	**$MEF_{enteric}$ (kg/h/year)**	**MEF_{manure} (kg/h/year)**	**Weight (kg)**	**$MEF_{enteric}$ (kg/h/year)**	**MEF_{manure} (kg/h/year)**
Breeding rams	78.0	10.5	0.0032	110.0	15.0	0.005	78.1	10.5	0.0032	58.0	7.62	0.0022
Breeding ewes	42.1	5.79	0.0017	54.5	7.4	0.0022	50.3	6.83	0.002	38.4	5.27	0.0015
Young rams	62.6	8.25	0.0025	59.5	10.5	0.0032	54.3	6.94	0.0021	42.4	5.6	0.0016
Young ewes	34.0	4.59	0.0013	44.0	5.80	0.002	38.0	5.07	0.0014	32.4	4.4	0.0012
Weaners	30.0	4.12	0.0011	25.0	3.55	0.001	30.0	4.12	0.0011	26.8	3.76	0.0010
Lambs	18.0	2.76	0.0007	18.0	2.76	0.0007	18.0	2.76	0.0007	18.0	2.76	0.0007

MEF: methane emissions factor; kg/h/year: kg/head/year.

Table 5 Estimated methane emissions of commercial sheep in South African according to provinces, based on 2010 population figures (Gg/year)

Breed Type		**Western Cape**	**Northern Cape**	**Free State**	**Eastern Cape**	**KwaZulu-Natal**	**Mpumalanga**	**Limpopo**	**Gauteng**	**North West**	**Total**
Merino	Population	1 245 804	2 806 729	2 236 117	3 355 781	353 650	803 167	118 342	47 704	320 166	11 287 460
	Enteric methane	8.08	18.60	14.7	21.7	2.28	5.17	0.71	0.31	2.10	73.7
	Manure methane	0.0022	0.005	0.004	0.006	0.00061	0.001	0.0002	8.2x10^{-5}	0.0006	0.0197818
Other wool	Population	460 721	1 037 980	826 958	1 241 030	130 786	297 026	43 765	17 642	118 403	4 174 312
	Enteric methane	3.58	8.23	6.52	9.63	1.01	2.29	0.34	0.14	0.93	32.7
	Manure methane	0.001	0.0023	0.0018	0.0026	0.0003	0.0006	9.345x10^{-5}	3.697x10^{-5}	0.0003	0.0089172
Non wool	Population	670 854	1 511 398	1 204 129	1 807 058	190 438	432 498	63 726	25 688	172 407	6 078 196
	Enteric methane	4.86	11.18	8.86	13.1	1.37	3.11	0.45	0.18	1.26	44.4
	Manure methane	0.001	0.003	0.002	0.004	0.0004	0.0008	0.0001	5x10^{-5}	0.00034	0.0118857
Karakul	Population	2 761	6 219	4 955	7 436	784	1 780	262	106	709	25 012
	Enteric methane	0.0163	0.0376	0.0297	0.0438	0.0046	0.0104	0.0382	0.0006	0.0042	0.1855
	Manure methane	4.4x10^{-6}	1.01x10^{-5}	7.9x10^{-6}	1.2x10^{-5}	1.2x10^{-6}	2.8x10^{-6}	9.5x10^{-6}	1.6x10^{-7}	1.13x10^{-6}	4.9x10^{-5}

Table 6 Estimated methane emissions of communal sheep in South African according to provinces, based on 2010 population figures (Gg/year)

Breed Type		**Western Cape**	**Northern Cape**	**Free State**	**Eastern Cape**	**KwaZulu-Natal**	**Mpumalanga**	**Limpopo**	**Gauteng**	**North West**	**Total**
Merino	Population	176 022	396 568	315 945	474 145	49 968	113 481	16 721	6 740	45 237	1 594 827
	Enteric methane	0.84	1.95	1.54	2.24	0.23	0.53	0.10	0.03	0.22	7.68
	Manure methane	2.4x10^{-4}	5.4x10^{-4}	4.3x10^{-4}	6.3x10^{-4}	6.6x10^{-5}	1.5x10^{-4}	2.7x10^{-5}	9x10^{-6}	6.1x10^{-5}	2.2x10^{-3}
Other wool	Population	65 096	146 658	116 842	175 348	18 479	41 967	6 184	2 493	16 729	589 796
	Enteric methane	0.37	0.85	0.67	0.98	0.10	0.23	0.06	0.01	0.10	3.38
	Manure methane	1.1x10^{-4}	2.4x10^{-4}	1.9x10^{-4}	2.8x10^{-4}	3x10^{-5}	6.8x10^{-5}	1.6x10^{-5}	4.02x10^{-6}	2.7x10^{-5}	9.7x10^{-4}
Non wool	Population	94 786	213 548	170 134	255 323	26 907	61 109	9 004	3 630	24 360	858 801
	Enteric methane	0.50	1.16	0.91	1.33	0.14	0.32	0.07	0.02	0.13	4.58
	Manure methane	1.4x10^{-4}	3.3x10^{-4}	2.6x10^{-4}	3.8x10^{-4}	4.01x10^{-5}	9.1x10^{-5}	1.9x10^{-5}	5.4x10^{-6}	3.7x10^{-5}	1.3x10^{-3}
Karakul	Population	390	879	700	1 051	111	256	37	15	100	3 539
	Enteric methane	1.7x10^{-3}	4x10^{-3}	3.1x10^{-3}	4.6x10^{-3}	4.8x10^{-4}	1.1x10^{-3}	1.6x10^{-4}	6.4x10^{-5}	4.4x10^{-4}	1.6x10^{-2}
	Manure methane	4.7x10^{-7}	1.1x10^{-6}	8.6x10^{-7}	1.3x10^{-6}	1.3x10^{-7}	3.1x10^{-7}	7.2x10^{-6}	1.8x10^{-8}	1.2x10^{-7}	1.2x10^{-5}

The methane emission factors for commercial and emerging/communal sheep are presented in Tables 3 and 4. Other wool sheep (dual purpose breeds) have the highest methane emission factors (MEF) across all categories, followed by non-wool, Merino and Karakul sheep. Dual purpose rams have the highest overall MEF, 22.2 kg CH_4/head/year with an average of 10.6 kg CH_4/head/year across all animal classes (Table 3). Commercial Merino sheep make up approximately 46% of the national flock and have an average MEF of 8.26 kg CH_4/head/year, with rams yielding 14.7 kg CH_4/head/year and breeding ewes 8.07 kg CH_4/head/year. Emerging/communal sheep emissions are estimated to be 28% lower than those of commercial sheep (Table 4). The lower MEF of emerging/communal sheep is mainly owing to lower liveweights and differences in the quality of diets offered to animals.

The provincial methane emissions for South African commercial and emerging/communal sheep during 2010 are presented in Tables 5 and 6. The highest methane emissions were generated from the Eastern Cape, Northern Cape, Free State and Western Cape provinces, with 49, 42, 33 and 18 Gg, respectively. These emission figures correspond with the population figures of sheep in the relevant provinces.

The enteric methane emission factors reported in Tables 3 and 4 are higher than the IPCC (2006) default factors reported for sheep in Africa of 5 kg/head/year, but the manure emission factors are considerably lower than the IPCC (2006) default factors. The IPCC (2006) based emission factors on sheep with liveweights of 45 kg for developing countries. The liveweight of sheep in the commercial sectors (Table 3) is more representative of IPCC (2006) default factors for developed countries of 65 kg liveweight and

Table 7 Comparison of mean liveweights and estimated average methane emission factors (kg/head/year) for sheep

		Liveweight (kg)	**Enteric CH_4**	**Manure CH_4**
South Africa:				
Commercial	Merino	55.2	8.26	0.0023
	Other wool	74.1	10.6	0.007
	Non wool	56.1	8.37	0.0023
	Karakul	45.0	6.67	0.002
Communal	Merino	44.1	6.0	0.0043
	Other wool	45.1	7.51	0.0024
	Non wool	44.8	6.04	0.0035
	Karakul	36.0	4.9	0.0014
IPCC (2006)[1]				
	Developed countries	65.0	8.0	0.28
	Developing countries	45.0	5.0	0.15
Australia[2]		48.0	6.8	0.002
New Zealand[3]			11.0	0.11
UK [3]			5.0	0.11
India[4]	Male	30.4	4.0	0.18
	Female	30.4	4.0	0.18
China[5]	Breedable		7.1	
	Other		3.6	
Brazil[6]			5.0	0.15
Asia[5]			4.85	0.19

[1]IPCC (2006); [2] Australian National Inventory Report (2009); [3] New Zealand Greenhouse National Inventory Report (2010); [3] UK United Kingdom; [4] Sammy & Bhattacharya (2006); [5] Yamaji *et al*. (2003); [6] Lima *et al*. (2002).

enteric methane emission factors of 8 kg/head/year. The IPCC (2006) default factors for developing countries are representative of the South African emerging/communal sector, although the calculated enteric methane emission factors for emerging/communal sheep are higher than the IPCC (2006) default factor of 5 kg/head/year (Table 4). The use of country-specific methane emission factors for manure emissions according to the Australian National Inventory Report (2009) methodology could explain the differences in calculated manure emission factors for both commercial and communal sheep and the IPCC (2006) default factors. Penttilä *et al.* (2013) reported that dung beetles could potentially increase GHG emissions from livestock faeces voided on rangeland or veld, mainly due to increased N_2O emissions. The possible effect of dung beetles is noted but not included in the present inventory due to insufficient data under South African conditions.

The estimated methane emission factors are compared with published emission factors from developed and developing countries in Table 7. The average enteric emission factor for commercial sheep, including Karakul sheep, of 8.5 kg/head/year (9.09 kg/head/year excluding Karakul sheep) is higher than that of Australian sheep (6.8 kg/head/year) and sheep from the United Kingdom (5 kg/head/year), but lower than sheep emission factors from New Zealand (11 kg/head/year). These differences are likely to be owing to variations in age structures, breed types and diet qualities used to calculate the average emission factors from these sources. South African emission factors for sheep are not comparable with other developing countries such as India, Brazil, China and Asia (Table 7), mainly due to differences in liveweights of sheep. Indian sheep are reported by Swammy & Bhattacharya (2006) to have enteric methane emissions of 4 kg/head/year with average liveweights of 30.4 kg. These figures are comparable with the enteric emission factors of emerging/communal Karakul sheep with liveweights of 36 kg and enteric methane emission factors of 4.9 kg/head/year.

The calculated DMI of all categories of sheep is in the range of the IPCC (2006) guidelines of between 1% and 3% of body weight. Lassey (2007) measured enteric methane emission from sheep fed diets with similar digestibilities to South African diets using the SF_6 technique. The emission factors for South African sheep receiving diets of approximately 55% DMD are 0.41 g CH_4/kg LW/day and 0.39 g CH_4/kg LW/day for commercial and communal sheep, respectively. These figures are lower than those reported by Lassey (2007) of 0.45, 0.46 and 0.43 g CH_4/kg LW/ day for sheep fed diets of 61.2%, 54% and 69.3% DMD using the SF_6 technique.

Goats

Meat goats

The South African goat population of approximately 7 million animals consists of commercial and emerging/communal meat goats, Angora goats and milk goats comprising 24.6%, 60.8%, 14.3% and 0.3%, respectively, of the total national goat population. Goats are farmed with throughout South Africa. The Eastern Cape and Limpopo provinces are the largest goat-producing provinces in South Africa (DAFF, 2011). The Boer goat, Savanna and Kalahari Red are recognized as commercial meat goat breeds with the Saanen, Toggenburg and British Alpine goats being kept mainly for milk production (DAFF, 2011). South Africa is the largest mohair producer globally (Mohair South Africa, 2011) with approximately 1 million

Table 8 Estimated methane emission factors for commercial goats in South Africa

Animal class	Weight (kg)	Intake (kg/day)	MEF $_{enteric}$ (kg/h/year)	MEF $_{manure}$ (kg/h/year)
Breeding bucks	118.0	2.6	18.3	0.02
Breeding does	78.0	1.67	12.1	0.013
Young bucks	88.3	1.8	13.1	0.014
Young does	55.5	1.08	8.01	0.0084
Weaners	37.5	0.72	5.54	0.006
Kids	22.5	0.44	3.62	0.0034

MEF: methane emissions factor; kg/h/year: kg/head/year.

Angora goats farmed with commercially, mainly in the Western Cape, Eastern Cape and Northern Cape provinces. The methane emission factors for commercial and communal meat goats are presented in Tables 8 and 9.

Commercial goats have an average MEF of 10.1 kg CH_4/head/year, which is 37% higher than the average of 6.3 kg CH_4/head/year for emerging/communal goats. The higher emissions factors for all classes of commercial goats are due mainly to better selection, nutrition and health management, which give rise to heavier, more productive animals (Masika *et al.*, 1998). Although the emissions per kg product were not calculated in this publication, commercial goats will have a lower MEF per kg product when compared with communal goats. The average methane emission factor for commercial goats of 0.42 g CH_4/kg LW/day is

Table 9 Estimated methane emission factors for emerging/communal goats in South Africa

Animal class	**Weight (kg)**	**Intake (kg/day)**	**MEF $_{enteric}$ (kg/h/year)**	**MEF $_{manure}$ (kg/h/year)**
Breeding bucks	82.0	1.53	11.1	0.013
Breeding does	54.4	0.99	7.40	0.009
Young bucks	61.6	1.10	8.11	0.009
Young does	39.0	0.67	5.19	0.006
Weaners	26.0.	0.45	3.66	0.004
Kids	16.0	0.29	2.54	0.003

MEF: methane emission factor; kg/h/year: kg/head/year.

Table 10 Estimated methane emissions of meat type goats in South Africa according to provinces, based on 2010 population figures (Gg/year)

Province	**Commercial goats**			**Communal goats**		
	Population	**Enteric methane (Gg)**	**Manure methane (Gg)**	**Population**	**Enteric methane (Gg)**	**Manure methane (Gg)**
Western Cape	61 467	0.53	5.6x10-4	151 718	0.83	4.5x10-4
Eastern Cape	643 295	5.51	5.9x10-3	1 587 977	8.57	4.6x10-3
Northern Cape	143 953	1.26	1.3x10-3	355 356	2.0	1.1x10-3
KwaZulu-Natal	227 269	1.94	2.1x10-3	561 018	3.0	1.6x10-3
Free State	66 653	0.58	6.4x10-4	164 529	0.91	4.9x10-4
North West	201 583	1.75	1.9x10-3	497 623	2.74	1.5x10-3
Gauteng	10 924	0.09	9.9x10-5	26 972	0.14	7.83x10-5
Mpumalanga	24 580	0.21	2.2x10-4	60 687	0.32	1.8x10-4
Limpopo	348 820	3.0	3.3x10-3	861 081	4.23	2.3x10-3
Total	1 728 544	14.9	1.6x10-2	4 266 961	22.7	1.2x10-2

similar to the emissions of commercial sheep of 0.41 g CH_4/kg LW/day. This trend is also present between the emerging/communal goats and sheep emission figures. The emerging/communal goat enteric methane emissions per day of 0.37 g CH_4/kg LW is slightly lower than that of emerging/communal sheep of 0.39 g CH_4/kg LW/day as reported earlier.

In 2010 the Eastern Cape Province had the largest goat population, accounting for 37% of the national flock, followed by Limpopo, KwaZulu-Natal and North West with 20%, 13% and 11%, respectively. The remaining five provinces accounted for 30% of the national flock (DAFF, 2011). The provincial methane emissions of South African meat goats for 2010 are reported in Table 10. Eastern Cape represented 37.4% of the methane emissions originating from meat goats, which corresponds with the population data reported earlier (DAFF, 2011). The emerging/communal sector was responsible for 60.5% of the methane emissions generated from meat goats nationally, and accounted for 71% of the total national meat goat flock.

The majority of countries calculated goat emission factors for inventory purposes on a Tier 1 level according to the IPCC (2006) guidelines using IPCC default factors. The default factors adopted by the IPCC for goats are based on the work of Crutzen *et al.* (1986), who calculated the methane emission factor for goats from research by Panday (1981) in India on goats with a gross energy intake of 14 MJ per day. The average gross energy intake for commercial sheep in this study was 25.8 MJ/day, assuming a gross energy concentration of 18.4 MJ/kg DM (SCA, 1990). Gross energy intake of emerging/communal sheep was calculated as 15.5 MJ/day, yielding a herd average methane emission factor of 6.33 kg CH_4/head/year compared with the IPCC default factor of 5 kg CH_4/head/year.

Enteric methane emission factors from other developing countries are summarized in Table 11. The emission factors for India were sourced from experimental data (Singh & Mohini, 1996); emission factors from Thailand and China were sourced from country-specific figures based on IPCC guidelines (Dong *et al.*, 2000; Yamaji *et al.*, 2003) and Japanese figures are based on direct and indirect measurement techniques (Shibata *et al.*, 1993).

Table 11 Methane emission factors for goats in developing countries and IPCC default values

Country	Enteric CH_4 emission factor (kg/head/year)	Manure CH_4 emission factor (kg/head/year)	Reference
South Africa: Commercial (2010)	10.1	0.032	Table 5: Present estimation
South Africa: Communal (2010)	6.33	0.007	Table 6: Present estimation
South Africa: Commercial (2004)	5.0	0.20	Otter, (2010)
South Africa: Communal (2004)	5.0	0.17	Otter, (2010)
IPCC: Developed countries	5.0	0.20	IPCC (2006)
IPCC: Developing countries	5.0	0.17	IPCC (2006)
Brazil	5.0		Lima *et al.* (2002)
India	3.9		Singh & Mohini (1996)
Thailand	5.0		Yamaji *et al.* (2003)
China: Breedable	7.1		Dong *et al.* (2000)
China: Other	3.6		Dong *et al.* (2000)
Japan	4.1		Shibata *et al.* (1993)

The enteric methane emissions from South African commercial and communal goats are higher than the IPCC default values and those of other developing countries (Table 11). The goat emission factors from other developing countries are based on animals that are smaller than South African goats with lower DM intakes (Crutzen *et al.*, 1986; Singh & Mohini, 1996; Yamaji *et al.*, 2003). Their estimated goat emission factors, however, are comparable with sheep emission factors reported earlier with commercial animals producing 0.42 and 0.40 g CH_4/kg LW/day for goats and sheep (excluding Karakul sheep), respectively, and 0.37 and 0.40 g CH_4/kg LW/day for emerging/communal goats and sheep respectively in South Africa.

The estimated manure emission factors reported in Tables 8 and 9 are considerably lower than manure emission factors reported in Table 11 from international sources and the IPCC (2006) default values. These differences could be owing to the use of country-specific manure emission data according to Gonzalez-Avalos & Ruiz-Suarez (2001) and the Australian National Inventory Report (2009) methodology, which differ from the IPCC default manure emission factors.

Angora

Mohair South Africa (2011) estimated the national Angora goat population at 1 million. Angora goats are farmed with mainly for the production of mohair in three provinces, Eastern Cape, Western Cape and Northern Cape, with 72%, 27% and 1% of the population, respectively (Roets, 2004; Mohair South Africa, 2011). The methane emission factors for Angora goats are reported in Table 12. Breeding bucks had the highest total methane emission factors with 6.01 kg CH_4/head/year, but the lowest emissions per kg DM intake of 20.6 g CH_4/kg DMI, with Angora kids producing 24 g CH_4/kg DMI. Breeding does and young Angora goats produced 21.4 and 21.7 g CH_4/kg DMI/day. The average MEF for Angora goats across all classes was 4.2 kg CH_4/head/year, which is low compared with commercial and emerging/communal

Table 12 Estimated methane emission factors for South African Angora goats

Animal class	Weight (kg)	Intake (kg/ day)	$MEF_{enteric}$ (kg/h/year)	MEF_{manure} (kg/h/year)	Daily enteric CH_4 (g/kg DMI)
Breeding bucks	41.5	0.80	6.01	0.0062	20.6
Breeding does	30.0	0.61	4.76	0.005	21.4
Young bucks	29.5	0.57	4.51	0.004	21.7
Young does	22.5	0.46	3.64	0.003	21.7
Weaners	20.5	0.41	3.39	0.003	22.7
Kids	14.5	0.30	2.63	0.002	24.0

MEF: methane emission factor; kg/h/year: kg/head/year; DMI: dry matter intake.

Table 13 Estimated methane emissions of South African Angora goats according to provinces, based on 2010 population figures (Gg/year)

Province#	Commercial goats		
	Population	Enteric methane (Gg)	Manure methane (Gg)
Western Cape	270 000	$3.3x10^{-2}$	$1.01x10^{-3}$
Eastern Cape	720 000	2.8	$2.7x10^{-3}$
Northern Cape	10 000	$4x10^{-2}$	$3.84x10^{-5}$
Total	1 000 000	2.9	0.0037

Angora goats are commercially farmed with only in Western Cape, Eastern Cape and Northern Cape (Mohair South Africa, 2011).

meat goat emissions of 10.1 and 6.33 kg CH_4/head/year, respectively, but the average daily methane production per kg dry matter intake was slightly higher.

Table 13 reports on the provincial methane emissions from Angora goats in South Africa in 2010. Angora goats contributed 2.9 Gg to the methane emissions in 2010, with Eastern Cape being the largest contributor with 97% or 2.8 Gg.

Milk goats

The South African commercial milk goat industry is relatively small, with an estimated population of 21000 animals across all provinces, and a negligible methane emission contribution of 0.17 Gg per annum. Goats that are milked for personal consumption in emerging and communal production systems were incorporated in the emerging/communal meat goat population figures. The average methane emission factor for commercial milk goats in South Africa is 6.9 kg CH_4/head/year varying from 3.6 to 10.5 kg CH_4/head/year for kids to breeding bucks. Table 14 reports on the methane emission factors for milk goats in South Africa. The average weight and methane emission factor are comparable with those of emerging/communal meat goats, 45 kg vs. 46.5 kg and 6.9 kg CH_4/head/year vs. 6.3 kg CH_4/head/year, respectively.

Table 14 Liveweight, intake and estimated methane emission factors for South African milk goats

Animal class	Weight (kg)	Intake (kg/day)	$MEF_{enteric}$ (kg/h/year)	MEF_{manure} (kg/h/year)
Breeding bucks	72.5	1.45	10.5	0.009
Breeding does	48.0	1.16	8.48	0.007
Young bucks	53.0	1.03	7.65	0.006
Young does	40.5	0.78	5.94	0.005
Weaners	33.5	0.65	5.02	0.004
Kids	22.5	0.44	3.62	0.003

MEF: Methane emissions factor; kg/h/year: kg/head/year.

Table 15 Estimated methane emissions of milk goats in South Africa according to provinces, based on 2010 population figures (Gg/year)

Province	Commercial milk goats		
	Population	Enteric methane (Gg)	Manure methane (Gg)
Western Cape	7 329	0.047	3.7×10^{-5}
Eastern Cape	444	0.0029	2.24×10^{-6}
Northern Cape	9 296	0.061	4.74×10^{-5}
KwaZulu-Natal	1 162	0.0075	5.85×10^{-6}
Free State	1 119	0.0073	5.69×10^{-6}
North West	598	0.0039	3.03×10^{-6}
Gauteng	444	0.0029	2.2×10^{-6}
Mpumalanga	58	0.0004	2.97×10^{-7}
Limpopo	387	0.04	1.96×10^{-6}
Total	20 837	0.172	1.1×10^{-4}

The provincial methane emissions of South African commercial milk goats in 2010 are presented in Table 15. The Northern Cape and Western Cape provinces accounted for approximately 80% of the total methane emissions from milk goat production systems in South Africa.

The methane emission factor reported in Table 14 for breeding does (8.48 kg CH_4/head/year) is higher than emissions reported by Singh & Mohini (1996) of 4.99 kg CH_4/head/year for milking goats older than a year. Milk goat breeding does had the highest methane emission (g CH_4/kg LW) across all adult goat breeds, producing 0.48 g CH_4/kg LW in South Africa. This is probably owing to the higher DMD of diets fed to breeding and lactating milk goat does. Pelchen & Peters (1998) reported a rise in sheep methane emissions (g/day) with an increase in digestibility of rations up to approximately 72% DMD, with a significant decrease in methane emissions if diet DMD was increased above 72%.

Karakul sheep and Angora goats apparently are the least efficient small stock breeds in terms of daily methane production, producing the highest enteric methane emissions per kg DM intake for both South African sheep and goat breeds. Commercial dual purpose sheep apparently are the lowest methane emitters per kg DM intake at 20.5 g CH_4/kg DMI/day. Table 16 reports on the calculated daily enteric methane production per kg DM intake of small stock in South Africa.

Table 16 Estimated daily enteric methane production per kg DM intake of South African small stock breeds

Small stock	Breed	Commercial CH_4 production	Communal CH_4 production
Sheep	Merino	20.7	21.3
	Other wool	20.5	21.0
	Non wool	20.6	21.2
	Karakul	20.9	21.7
Goats	Meat goats	19.8	20.7
	Angora	21.5	
	Milk	20.5	

The variation among breed types within production systems is very small, as shown in Table 15. Meat goats produced the least amount of enteric methane per kg DM intake in both commercial and emerging/communal production systems with Karakul sheep the highest enteric methane contributors per kg DM intake in both systems.

Conclusion

Small stock is a major source of methane emissions in the South African agricultural sector. A detailed, updated methane emissions inventory on a provincial basis was developed using improved country specific emission factors based on the IPCC good practice guidelines. The sheep industry contributed an estimated 167 Gg of methane in 2010, and the goat industry 40.7 Gg, with a combined 15.6% of South Africa's total livestock methane emissions in 2010. The commercial sheep industry contributed an estimated 91% of sheep emissions, whereas 56% of goat methane emissions originated from the emerging/communal sector. Previous inventories underestimated the emissions contribution from small stock as the IPCC default values for African countries are not representative of South African sheep and goat production systems. Neither South African sheep nor goat commercial or communal emission factors were comparable with other developing and developed countries. The differences between the current inventory and previous inventories using default Tier 1 emission factors are between 20% and 70% for sheep and 25% and 100% for goat emissions. Efforts have been made to reduce uncertainties in activity data, but uncertainties will remain as no emission measurements exist for South Africa. It is important to conduct emission studies on enteric fermentation and manure management for small stock in all provinces and on all types of small stock to produce accurate baseline figures, which is critical to future mitigation protocols.

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Appendix A

Table A.1 Ratio of veld types per province (Tainton, 1981; 1999)

	Sweetveld	Sourveld	Mixed veld
Western Cape	0.5	0.3	0.2
Northern Cape	1.0	0	0
Eastern Cape	0.35	0.35	0.3
Free State	0.8	0.1	0.1
KwaZulu-Natal	0.2	0.6	0.2
Mpumalanga	0.15	0.7	0.15
Limpopo	0.6	0.2	0.2
Gauteng	0.2	0.6	0.2
North West	0.7	0.25	0.05

Table A.2 Veld digestibilities (Dugmore & Du Toit, 1988; De Waal, 1990; O'Reagain & Owen-Smith, 1996)

	Sweetveld	Sourveld	Mixed veld
Spring	65	65	65
Summer	60	60	60
Autumn	55	50	50
Winter	50	45	45

Appendix B

Table B.1 Liveweights of commercial sheep breeds (NWGA, 2011 and Breed associations)

Animal class	**Merino**	**Other wool**	**Non wool**	**Karakul**
	weight (kg)	**weight (kg)**	**weight (kg)**	**weight (kg)**
Breeding ram	**97.5**	**137.5**	**97.5**	**72.5**
Breeding ewe	**53.0**	**68.0**	**63.25**	**48.0**
Young ram	**78.4**	**98.3**	**68.3**	**53.0**
Young ewe	**42.5**	**55.5**	**47.5**	**40.5**
Weaners	**37.5**	**31.5**	**37.5**	**33.5**
Lambs	**22.5**	**22.5**	**22.5**	**22.5**

Table B.2 Liveweights of communal sheep breeds

Animal class	**Merino**	**Other wool**	**Non wool**	**Karakul**
	weight (kg)	**weight (kg)**	**weight (kg)**	**weight (kg)**
Breeding rams	**78.0**	**110.1**	**78.1**	**58.0**
Breeding ewes	**42.1**	**54.5**	**50.3**	**38.4**
Young rams	**62.6**	**59.5**	**54.3**	**42.4**
Young ewes	**34.0**	**44.0**	**38.0**	**32.4**
Weaners	**30.0**	**25.0**	**30.0**	**26.8**
Lambs	**18.0**	**18.0**	**18.0**	**18.0**

Table B.3 Proportion breeding ewes per season (lambing seasons) per province – commercial sheep

Province	**Spring %**	**Summer %**	**Autumn %**	**Winter %**
Western Cape				**100**
Northern Cape			**100**	
Eastern Cape	**20**		**80**	
Free State	**20**		**80**	
KwaZulu-Natal	**20**		**80**	
Mpumalanga	**20**		**80**	
Limpopo	**20**		**80**	
Gauteng	**20**		**80**	
North West	**20**		**80**	

Table B.4 Proportion breeding ewes per season (lambing seasons) per province – communal sheep

Province	Spring %	Summer %	Autumn %	Winter %
Western Cape	25	25	25	25
Northern Cape	25	25	25	25
Eastern Cape	25	25	25	25
Free State	25	25	25	25
KwaZulu-Natal	25	25	25	25
Mpumalanga	25	25	25	25
Limpopo	25	25	25	25
Gauteng	25	25	25	25
North West	25	25	25	25

Appendix C

Table C.1 Mean liveweights for commercial meat goats

Animal class	Weight (kg)	$MEF_{enteric}$ (kg/h/year)	MEF_{manure} (kg/h/year)
Breeding bucks	118	18.3	0.02
Breeding does	78.0	12.1	0.013
Young bucks	88.3	13.1	0.014
Young does	55.5	8.0	0.0084
Weaners	37.5	5.5	0.006
Kids	22.5	3.6	0.0034

MEF: Methane emissions factor; kg/h/year: kg/head/year.

TableC.2 Mean liveweights for communal meat goats

Animal class	Weight (kg)
Breeding bucks	82
Breeding does	54.4
Young bucks	61.6
Young does	39
Weaners	26
Kids	16

Table C.3 Mean liveweights of Angora goats

Animal class	Weight (kg)
Breeding bucks	41.5
Breeding does	30.0
Young bucks	29.5
Young does	22.5
Weaners	20.5
Kids	14.5

Table C.4 Mean liveweights of South African milk goats

Animal class	**Weight (kg)**
Breeding bucks	**72.5**
Breeding does	**48.0**
Young bucks	**53.0**
Young does	**40.5**
Weaners	**33.5**
Kids	**22.5**