Direct greenhouse gas emissions of the game industry in South Africa

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Abstract

Previous greenhouse gas (GHG) inventories did not include game as an emissions source. Recently game farming has become a recognized commercial enterprise in the agricultural sector in South Africa, contributing approximately R10 billion to the sectorial gross domestic product. The objective of this study was to estimate methane (CH_4) and nitrous oxide (N_2O) emissions from privately owned game animals based on international recognized methodologies. The emissions were calculated on the basis of a large stock unit (LSU) selecting different quality diets. Daily enteric methane emissions were estimated as 0.28, 0.22, and 0.18 kg CH_4/LSU/day consuming diets of 55%, 65% and 75% digestibility, respectively. The game industry contributed an estimated 131.9 Giga grams (Gg) of methane annually to agricultural emissions with the provinces of Limpopo, Eastern Cape and Northern Cape being the three largest contributors with 43.4, 37.3 and 21 Gg methane, respectively. The total privately owned game population was estimated at 299 1370 animals, utilizing 20.5 million hectares.

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Introduction

Game or wild ungulates have always inhabited southern Africa, although the population size has fluctuated greatly over the past 100 years. The establishment and growth of the private game industry is largely responsible for an increase in the number of game in recent years (Eloff, 2002; Bothma & Van Rooyen, 2005). Similarly, the industry has shown a steady growth in the number of game farms from 2 280 in 1980 to 9 000 in 1992 (Nell, 2003) and approximately 10 000 currently (G. Dry, 2013, Pers. Comm., Wildlife Ranching South Africa, P.O. Box 23073, Gezina, 0031, South Africa). The private game ranching industry occupies 16.8% (20 500 000 ha) of South Africa's total land area. This figure equates to 24% of South Africa's 84 million hectares of grazing land (Dry, 2011). This is more than double the area of officially declared conservation areas and approximately fivefold the area of the national parks (Carruthers, 2004).

Game farming or ranching has become an organized and recognized enterprise in the agricultural industry (Eloff, 1996; Van Der Waal & Dekker, 2000). According to a recent article by Van Rooyen (2013) the wildlife industry ranked fifth largest in the agricultural sector, contributing R10 billion to the country's gross domestic product (GDP). Game farming is defined as an agricultural system in which wild animals are maintained in order to harvest by-products such as meat and skins in a domesticated or semi-domesticated manner by being enclosed in relatively small areas and provided with regular supplementary feeding and water (Carruthers, 2004; Du Toit, 2007). Part of the success of the industry is the ability of game to produce higher returns, compared to conventional livestock farming, under particular circumstances that may enhance the utilization of land with low agricultural potential (ABSA, 2003).

Herbivorous game, with the exception of elephant, rhinoceros, hippopotamus, zebra, warthogs and bushpigs, are ruminants. Ruminants contribute to greenhouse gas (GHG) emissions through methane

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emissions directly from digestive processes and methane (CH_4) and nitrous oxide (N_2O) emissions originating from manure. The quantity of CH_4 produced by ruminants is influenced by the level of intake, composition of the diet, and level of production of the animal. Game species select for diet quality in accordance with their feeding habits, and were classified by Hofmann (1973) as bulk and roughage eaters (grazers), selectors of concentrated herbage (browsers) and intermediate feeders (grazing and browsing). These three groups typically select diets with an approximate digestibility of 55%, 75% and 65%, respectively (Meissner *et al.*, 1983). These differences in diet quality influence energy intake as well as the amount of gross energy intake, which is lost as methane and thus methane emissions.

Game is considered a source of anthropogenic emissions. Previous GHG inventories for the livestock sector in South Africa did not include privately owned game as an emission source. The game industry has developed into a commercial farming sector, and emissions from all such sectors in the livestock industry need to be included in order to provide a complete and representative emissions inventory of the livestock sector. The aim of this study was to calculate methane emissions originating from privately owned game.

Methodology

Various sources have reported on the privately owned game population, which have varied from as low as 1.7 million (Van der Merwe & Saayman, 2003), to 2.5 million (G. Dry, 2013, Pers. Comm., Wildlife Ranching South Africa, P.O. Box 23073, Gezina, 0031, South Africa), to 9 million (NAMC, 2006), to 16 million (Van Rooyen, 2013), to as high as 18.6 million (ABSA, 2008). The majority of sources agreed on the surface area under private game nationally of 20.5 million hectares (NAMC, 2006; ABSA, 2008; Cousins *et al.*, 2008, Dry, 2011). Owing to the large variations in literature quotes of the number of privately owned game in South Africa, game emissions were calculated according to the grazing capacity of an area on a provincial basis in terms of large stock units (LSU) and were not based on individual population figures.

The calculations followed the principles of the IPCC (2006) guidelines. Grazing capacity is defined as the area of land required to maintain a single LSU over an extended number of years without deterioration of the vegetation or soil. It was assumed that wildlife farmers stock their farms according to the ecological carrying capacity of the farm. Table 1 indicates the number of exempted game farms in South Africa, based on data from 2000, according to Eloff (2002) and Van der Merwe & Saayman (2003).

Table 1 Proportion of exempted game farms in South Africa (Eloff, 2002; Van der Merwe & Saayman, 2003)

Province (year 2000)	% of game farms	% of game farms according to hectares
Free State	3.56	1.43
Limpopo	49.0	32.1
North West	6.72	3.51
Mpumalanga	4.05	2.66
Gauteng	1.42	0.79
KwaZulu-Natal	1.78	1.63
Eastern Cape	12.3	8.51
Northern Cape	19.5	46.8
Western Cape	1.62	2.56
Total	100	100

Similar ratios on the percentage of game farms per province have been reported by ABSA (2008) and Dry (2011), although the total surface area of the game farms has increased from 10.4 million hectares in 2000 (Eloff, 2002) to 20.5 million hectares currently (Dry, 2011). The estimation of the surface area of private game farms per province was based on the ratio reported in Table 1 and the national total of 20.5

million hectares. The emissions calculations in this study were based on surface area under game farms incorporating carrying capacity of regions, owing to the uncertainty in game population numbers.

Provinces in South Africa were divided into five ecological regions, namely Grassland, Lowveld, Bushveld, Kalahari and Karoo, according to Bredenkamp *et al.* (1996). Grassland is defined as the higher inner plateau with an annual rainfall of between 500 mm and 800 mm, dominated by various grass types with limited trees and shrubs. The Lowveld, Bushveld and Kalahari regions are grouped as savannah areas. The Lowveld region covers low-lying areas east of the Northern Drakensberg escarpment with an annual rainfall of between 400 mm and 600 mm. The Bushveld region refers to the northern parts of South Africa, west of the Drakensberg escarpment, including the Limpopo valley, with an annual rainfall of between 300 mm and 600 mm. The Kalahari region is classified as arid savannah, with an annual rainfall of between 200 mm and 400 mm per annum. The western part of the Karoo region is classified as semi-desert with an annual rainfall of less than 200 mm (Bredenkamp *et al.*, 1996; ABSA, 2003). The ecological carrying capacity (ha/LSU) of these regions was reported by ABSA (2003) as 4, 12, 15, 30, and 55 for Grassland, Lowveld, Bushveld, Kalahari and Karoo regions, respectively. The average farm size was estimated according to data reported by Van der Merwe & Saayman (2003). The area per ecological region per province is reported in Table 2.

Table 2 Average game farm size and surface area of ecological regions per province in South Africa

Province	Total area (ha) ('000)	Ave farm size (ha)	Surface area/ ecological region/ province				
			Grassland (ha)	Lowveld (ha)	Bushveld (ha)	Kalahari (ha)	Karoo (ha)
Free State	287	821	206 066			18 942	61 992
Limpopo	6 581	1 340	210 576	921 270	5 461 815	6 581	
North West	718	1 073	208 075		157 850	351 575	
Mpumalanga	554	146	354 240	132 840	66 420		
Gauteng	164	1 140	127 104		36 900		
KZN	328	1 876	118 080	101 680	108 240		
Eastern Cape	1 743	1 413	702 809		476 284		563 409
Northern Cape	9 594	4 921	32 620			2 830 230	6 732 110
Western Cape	533	3 234	5 330		26 650		501 020

KZN: KwaZulu-Natal.

It was assumed that approximately 30% of the farms per province are larger than the average farm size according to research by Van der Waal & Dekker (2000). The habitat and size of the farm influence the minimum herd size and relative species distribution of a game farm (Appendices 1A & 1B). The total LSUs according to the ecological carrying capacity on a provincial basis are given in Table 3. A LSU is defined as a steer of 450 kg, which gains 500 g/day on a pasture with a mean digestibility (DE) of 55% (Meissner *et al.*, 1983). The proportion of grazers, browsers and mixed feeders as a percentage of total large stock units per ecological region is reported in Table 4. The relative distribution of animal species on private game farms is different from that of national parks in South Africa (ABSA, 2003) and varies according to the size of the farm. The relative distributions of animal species and herd size per ecological region for small and large farms are reported in Appendices 1A and 1B.

Enteric methane emissions originating from game were calculated based on dry matter intake (I), (kg DM/head/day). The daily intake of animal types was calculated based on metabolizable energy requirements (MJ/day) of large stock units according to Meissner *et al.* (1983). The daily metabolizable energy (ME) requirements (MJ/day) of animals selecting diets with various levels of digestible energy concentrations were based on the net energy requirements of an LSU and the efficiency coefficients of ME utilization at a certain level of production, according to Meissner *et al.* (1983). Daily intake per animal type was calculated by dividing the ME requirement (MJ/day) by the ME concentration (MJ/ kg) of the selected diet.

Table 3 Distribution of large stock units per province according to ecological carrying capacity

Province	Large stock units		
	Large farm	Small farm	Total
Free State	15 982	36 946	52 928
Gauteng	10 271	23 965	34 236
Limpopo	148 127	345 631	493 758
Mpumalanga	31 217	72 841	104 058
KwaZulu-Natal	13 563	32 396	45 959
Western Cape	3 666	8 554	12 220
Northern Cape	67 470	157 429	224 899
North West	22 279	51 982	74 261
Eastern Cape	64 803	334 382	399 185

Table 4 Animal types per ecological region as a percentage of large stock units (ABSA, 2003)

Animal type	Ecological region				
	Grassland	Lowveld	Bushveld	Kalahari	Karoo
Low selective grazers	20	25	20	10	2
High selective grazers	50	30	30	65	60
Mixed feeders	28	25	30	20	35
Browsers	2	20	20	5	3

Daily enteric methane (M), (kg/head/day) production was calculated according to Kurihara *et al.* (1999) based on emissions from cattle fed tropical grass species as:

$$M = (34.9 \times I - 30.8)/1000$$

Methane emissions from manure (M), (kg/head/day) of all game were calculated according to ANIR (2009) as:

$$M = I \times (1 - DMD) \times MEF$$

Where: I = dry matter intake (kg DM/head/day)
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.
DMD = diet digestibility (55% for grazers, 65% for browsers and 75% for concentrate selectors).

Game production systems are mainly extensive and manure is deposited directly on veld or rangeland. According to the IPCC (2006), N_2O emissions from manure deposited on rangeland or veld are reported under the managed soils section in the national inventory report format and not under livestock emissions. Nitrous oxide emissions originating from faeces and urine deposited on rangeland was calculated according to the ANIR (2009).

Results and Discussion

Game farming has become a recognized agricultural enterprise (Bothma, 1995; Eloff, 1996; Van der Waal & Dekker, 2000) but previous agricultural GHG inventories did not include game farming as an emission source (Blignaut *et al.*, 2005; Otter, 2010). The daily intake, estimated CH_4 emissions originating from enteric fermentation and manure, and estimated N_2O emissions from faecal matter deposited on soils from large stock units selecting various diets are presented in Table 5.

Table 5 Estimated daily intake, methane and nitrous oxide emissions of large stock units selecting different diet qualities

Animal class	Diet digestibility (%)	Intake (kg DM/day)	Enteric CH_4 (kg/head/day)	Manure CH_4 (kg/head/day)	Soil N_2O (kg/head/day)
Grazer	55	8.81	0.277	5.6×10^{-5}	5.4×10^{-4}
Intermediate feeders	65	7.08	0.216	3.5×10^{-5}	7.4×10^{-4}
Browsers	75	5.89	0.175	2.1×10^{-5}	1.07×10^{-3}

Every farm differs and has its own unique carrying capacity and game composition potential. The number of animals kept on a land unit is determined by the size of the habitat area, the carrying capacity of the unit, the social and spatial needs of the animals, as well as the interaction and composition of the animal species (Furstenburg, 2011). Domestic livestock have lost their natural social structure and territorial behaviour over the years, and carrying capacity is based on fodder production, consumption and veld type (Furstenburg, 2011). The carrying capacity on game farms incorporates animal social needs and habitat requirements. The use of grazing capacity as a base for the calculations is a source of uncertainty, as there is a difference between the grazing capacity of the veld and the stocking rate. Grazing capacity refers to the true number of animals the vegetation can sustain, and the stocking rate to the number of animals the farm manager perceives it can sustain (Smit, 2012). Smit (2012) stated that the use of LSU values for herbivorous game species does not allow for ecological separation, and overlooks the potential for using the specialized and complementary resource-use habits of wildlife to maximize veld utilization. The approach, however, is based on sound scientific principles and the error associated with an approach based on individual animal numbers will be larger owing to the large variation in reported game population numbers in South Africa.

The methane emissions of wildlife on private game farms per province are presented in Table 6. The game industry contributes an estimated 132 Gg in methane emissions per annum. These figures were calculated based on the average carrying capacity of game farms in each province. Limpopo was the largest contributor in terms of methane emissions from farmed wildlife followed by Eastern Cape and Northern Cape, with 43.4 Gg (32.9%), 37.3 Gg (28.3%) and 21 Gg (15.9%) respectively of the total emissions. The emission calculations were based on LSUs as defined by Meissner *et al.* (1983). This may lead to a possible over-estimation of game emissions, as not all game animals are ruminants. Northern Cape has the largest surface area under private game farming (46.8%), followed by Limpopo (32.1%) and Eastern Cape (8.5%). The difference between provincial ranking according to surface area and methane emissions is because of the average carrying capacity of the provinces. Northern Cape has the largest surface area under private game farming, but it ranks only third in terms of methane emissions originating from private game. This is owing to the relatively low carrying capacity of the Karoo (55 ha/LSU), which covers approximately 70% of Northern Cape, compared to the carrying capacity of the Bushveld (15 ha/LSU) and Grassland (4 ha/LSU) which cover approximately 86% and 68% of Limpopo and Eastern Cape, respectively.

The methane emissions per individual animal were calculated based on the energy requirements as described above. The calculated dry matter intake as a percentage of liveweight is lower than that reported by Smit (2012) for game species. Meissner (1982) indicated that the feed intake of wild ungulates in subtropical regions is less than that of domestic livestock of comparable size. Curtzen *et al.* (1986) reported annual methane emissions of 34 kg, 50 kg, 5 kg, 26 kg, and 5 kg for buffalo, giraffe, impala, elephant and zebra, respectively. These estimates are considerably lower than those calculated in this study and reported in Table 7. The emission estimates reported by Curtzen *et al*. (1986) were based on animals with lower liveweights and gross energy intakes than when compared with those reported in Table 7. The CH_4 emissions for elephant and zebra were based on emission values of horses, which have similar digestive systems, as 3.5% of digestible energy intake (Curtzen *et al*., 1986). The emissions from black wildebeest, tsessebe, blesbok, impala and springbok were based on the equation developed by Howden & Reyenga (1987) based on respiration chamber experiments on sheep in Australia. Warthog emissions were estimated according to the IPCC (2006) based on pigs in developing countries. All other methane emission estimates for game (giraffe, eland, buffalo, kudu, waterbuck and blue wildebeest) reported in Table 7 were based on an equation developed by Kurihara *et al*. (1999) based on cattle fed tropical pastures.

Table 6 Estimated methane emissions (Gg/year) and number of large stock units per animal class and province in South Africa

Province	**Animal class**	**Large stock units**	**Enteric CH_4 (Gg/year)**	**Total CH_4 (Gg/year)**	**% contribution to total emissions**
Free State	Grazers	37 019	3.74		
	Mixed feeders	14 824	1.17	4.98	3.78
	Browsers	1 085	0.07		
Gauteng	Grazers	23 473	2.37		
	Mixed feeders	9 635	0.76	3.21	2.43
	Browsers	1 128	0.07		
Limpopo	Grazers	261 302	26.4		
	Mixed feeders	143 214	11.3	43.4	32.9
	Browsers	89 243	5.7		
Mpumalanga	Grazers	70 295	7.11		
	Mixed feeders	28 893	2.28	9.70	7.35
	Browsers	4 871	0.31		
KwaZulu-Natal	Grazers	29 457	2.98		
	Mixed feeders	12 758	1.01	4.22	3.20
	Browsers	3 743	0.24		
Western Cape	Grazers	7 470	0.76		
	Mixed feeders	4 095	0.32	1.12	0.85
	Browsers	655	0.04		
Northern Cape	Grazers	152 354	15.4		
	Mixed feeders	63 993	5.05	21	15.9
	Browsers	8 552	0.55		
North West	Grazers	50 464	5.10		
	Mixed feeders	20 066	1.58	6.92	5.25
	Browsers	13 738	0.24		
Eastern Cape	Grazers	272 337	27.5		
	Mixed feeders	113 110	8.92	37.3	28.3
	Browsers	126 746	0.88		
Total		1 441 504	131.9	131.9	100

Giraffe and eland had comparable daily CH_4 emission factors (g CH_4/kg LW/day) to commercial beef bulls and cows with similar liveweights (LW), according to Du Toit *et al*. (2013a), with 0.46 g CH_4/kg LW/day compared to 0.42 g CH_4/kg LW/day for giraffe and commercial bulls and 0.51 g CH_4/kg LW/day compared to 0.53 g CH_4/kg LW/day for eland and commercial beef cows, respectively. Buffalo had higher calculated daily CH_4 emission factors (0.67 g CH_4/kg LW/day) compared to commercial beef cows (0.53 g CH_4/kg LW/day) with similar liveweights (Du Toit *et al*., 2013a). The daily CH_4 emission factors of smaller antelope reported in Table 7 were compared to commercial small stock emission factors with similar liveweights according to Du Toit *et al*. (2013b). Black wildebeest and tsessebe had estimated daily CH_4 emission factors (g CH_4/kg LW/day) that are similar to those of commercial dual purpose breeding rams, but lower emission factors than those of commercial breeding goat bucks with 0.39, 0.38, 0.37 and 0.43 for black wildebeest, tsessebe, commercial dual purpose breeding rams and breeding goat bucks, respectively. Impala and springbok had numerically higher estimated daily CH_4 emissions factors (g CH_4/kg LW/day) than commercially farmed goats with similar liveweights as reported by Du Toit *et al*. (2013b) with 0.50 and 0.48 compared to 0.40 and 0.44 for impala, springbok, young does and kids, respectively.

Table 7 Approximate liveweight (LW), large stock unit (LSU) substitution, diet digestibility, intake (% of live weight) and methane emissions of selected game species

Species	Weight (kg)#	LSU	Diet DE* (%)	Intake (%/LW)	CH_4 (kg/head/year)	CH_4 (g/kg LW/day)
Elephant	2 436	3.83	55	1.4	81.0	0.10
Giraffe	826	1.51	65	1.4	136	0.46
Eland	528	1.08	65	1.6	93.7	0.51
Buffalo	466	1.08	55	2.1	113	0.67
Zebra	266	0.66	55	2.2	13.9	0.15
Kudu	155	0.44	65	2.2	31.3	0.56
Waterbuck	150	0.41	55	2.5	35.9	0.67
Blue wildebeest	153	0.43	75	1.8	24.8	0.44
Black wildebeest	106	0.30	75	1.9	14.3	0.39
Tsessebe	105	0.03	65	1.8	13.8	0.38
Blesbok	62	0.19	75	2.0	9.08	0.43
Warthog	59	0.21	75	2.4	2.22	0.18
Impala	42	0.15	75	2.4	7.40	0.50
Springbok	28	0.09	75	2.2	4.72	0.48

Animal live weight and daily energy requirements used in intake calculations were sourced from Meissner *et al*. (1983). * DE: feed digestibility.

Tables 8a and 8b reports on the estimated South African privately owned game population according to province, based on the norms presented by ABSA (2003) in Appendices 1A and 1B. The total game population is estimated at 2 991 370 animals. This is in line with the figure reported by Dry (2011) of 2.5 million animals, but smaller than other figures reported in the literature (NAMC, 2006; ABSA, 2008: Van Rooyen, 2013).

Annual enteric methane emissions for individual game species reported in Appendix 2 were calculated based on daily intake using the equations of Howden & Reyenga (1987), Kurihara *et al*. (1999), and the IPCC (2006), as discussed earlier. For hippopotamus and rhinoceros, the methane emissions were based on the daily methane emissions of elephant of 0.1 g CH_4/kg LW/day. The liveweights of game animals were sourced from Meissner *et al*. (1983) and Smit (2012). By basing the emission estimates on individual animal populations of approximately 3 million, the total methane emissions for the commercial game industry come to 59.9 Gg per year. This is considerably lower that the emission estimate based on LSUs and stocking rates of 132 Gg reported in Table 6. The variation in emission estimates is very large when game populations are

Table 8a Estimated game numbers per province based on norms reported by ABSA (2003)

Animal Species		Provinces									
		Gt	Mpum	NC	NW	EC	Lim	FS	KZN	WC	Total
Low selective grazers											
LSU/animal											
1.07	Buffalo	288	2075	862	625	1732	12475	439	1299	26	19821
2.24	Hippo	7	49	0	28	84	1232	0	48	5	1453
2.75	White Rhino	112	335	181	224	674	1574	170	143	9	3422
0.66	Zebra (Burchell)	9418	27447	2249	17151	111990	124411	14206	11704	841	319418
0.66	Zebra (Cape mountain)	0	0	16073	1536	308	29	106	0	276	18328
High selective grazers											
LSU/animal											
0.22	Blesbok	14444	40255	3707	23645	26836	23929	26836	13759	606	174017
0.56	Gemsbok	20	36	72194	4165	3515	3003	470	58	2942	86403
0.37	Red hartebeest	4 464	12273	37525	9814	11786	32248	8216	4588	1780	122694
0.25	Reedbuck	3325	9786	816	5833	7788	31718	5904	3968	240	69378
0.64	Roan	17	109	0	74	222	3100	0	110	12	3644
0.64	Sable	17	109	0	74	222	3100	0	110	12	3644
0.15	Springbok	21184	59040	274963	49914	51540	35382	41116	20180	11821	565140
0.38	Tsessebe	233	1468	0	998	2975	41769	0	1486	168	49097
0.5	Waterbuck	251	1581	0	1073	3203	44972	0	1600	181	52861
0.46	Wildebeest (black)	15543	43317	3989	25444	28878	25750	28878	14806	653	187258
0.5	Wildebeest (blue)	782	5593	80858	7917	13640	144896	527	5498	3844	263555

Gt: Gauteng; Mpum: Mpumalanga; NC: Northern Cape; NW: North West; EC: Eastern Cape; Lim: Limpopo; FS: Free State; KZN: KwaZulu-Natal; WC: Western Cape.

used, 50.05 Gg from 2.5 million animals to 336.34 Gg from 18.6 million animals. The type of diet selected by game, the amount of methane produced per unit of feed intake, and variation in daily feed intake are further causes of uncertainty when emission estimates are based on animal populations.

Table 8b Estimated game numbers per province based on norms reported by ABSA (2003)

Animal Species		Provinces									Total
		Gt	Mpum	NC	NW	EC	Lim	FS	KZN	WC	
Mixed feeders											
LSU/animal											
0.09	Duiker	2223	6660	19610	4888	7999	44604	3797	3146	1323	94250
1.08	Eland	7922	22061	46592	14226	18789	27678	14828	7795	3113	163004
5	Elephant	15	94	0	66	198	2754	0	96	11	3236
0.2	Impala	1292	9382	25000	8630	16486	240164	167	9190	933	311244
0.23	Nyala	0	1023	0	0	0	7093	0	783	0	8899
0.38	Ostrich	97	772	9857	940	1707	18525	64	742	490	33194
0.25	Reedbuck (mountain)	1156	3467	3595	2539	3114	17188	2006	1531	109	34705
0.25	Warthog	148	1594	9057	1756	1884	31080	61	1450	107	47137
Browse											
LSU/animal											
0.13	Bushbuck	114	954	0	486	1449	22001	0	907	82	25993
1.58	Giraffe	156	1072	269	699	1987	28537	2	1063	112	33897
0.07	Klipspringer	1160	3701	8108	2503	2954	15944	1736	1662	428	38196
0.54	Kudu	556	2386	8154	2407	4516	48619	933	1911	346	69828
0.13	Rhebuck (grey)	1800	5654	977	3314	3947	24798	2501	2527	153	45671
1.65	Rhino (Black)	9	56	129	54	114	1604	1	57	6	2030
0.06	Steenbuck	3371	10258	46959	6998	10842	49285	4680	4318	3245	139953
Total (a + b)		90124	272607	671724	198021	341379	1109462	157644	116533	33880	2991370

Gt: Gauteng; Mpum: Mpumalanga; NC: Northern Cape; NW: North West; EC: Eastern Cape; Lim: Limpopo; FS: Free State; KZN: KwaZulu-Natal; WC: Western Cape.

The CH_4 emissions estimates per species are reported in Appendix 2. As CH_4 emissions originating from manure of game are very low, it is not reported in the table in Appendix 2. Although the N_2O emitted from soil through the metabolism of manure and urine is not reported under livestock emissions according to the IPCC (2006) good practice guidelines, it is mentioned to provide a more complete scenario of emissions associated with game on privately owned land. Nitrogen in faecal matter is primarily in an organic form and must first be mineralized before it becomes a source of N_2O. The mineralization process occurs at significant rates in higher rainfall regions. However, the decay of faeces in drier areas is much slower, with faeces remaining largely intact for months to years (ANIR, 2009). The N_2O emissions from faeces and urine voided in rangeland were estimated at 0.39 Gg N_2O/year on a national scale using emission factors of 0.005 and 0.004 Gg N_2O-N/Gg N for faeces and urine, respectively, according to the ANIR (2009). Penttilä *et al.* (2013) reported that dung beetles could potentially increase GHG emissions from 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 Limpopo province had the largest emissions originating from game followed by Northern Cape and Eastern Cape provinces.

Conclusion

Game was not included in previous inventories, but was identified as a key CH_4 emissions source in the present inventory, contributing 132 Gg of CH_4. Nitrous oxide emissions from rangeland soils originating from faecal matter were estimated at 0.39 Gg N_2O/year. There is a great deal of uncertainty in the estimation of GHG emissions from game on game farms. To base the CH_4 emission estimation on the ecological carrying capacity of commercial game farms remains the soundest approach, as the variations in game population numbers and intake estimations are extremely large. Multiple sources agreed on the figure for the surface area under private game in South Africa of 20.5 million hectares and this appears the only justifiable basis for the emissions estimation.

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Appendix

Appendix 1A Minimum herd size and relative distribution of animal species per ecological region for larger farms (ABSA, 2003)

		Relative distribution of animal species as a % of LSU*				
Animal species	**Min. social herd size**	**Grassland**	**Lowveld**	**Bushveld**	**Kalahari**	**Karoo**
Low selective grazers		**20%**	**25%**	**20%**	**10%**	**2%**
Buffalo	15	15	50	15	30	
Hippo	15		10	10		
White Rhino	5	15	10	15	15	
Zebra (Burchell)	5	70	30	60		
Zebra (Cape mountain)	10				55	100
High selective grazers		**50%**	**30%**	**30%**	**65%**	**60%**
Blesbok	12	20				
Gemsbok	12			5	30	30
Red hartebeest	12	10		5	10	10
Reedbuck	8	5	5	5		
Roan	12		5	5		
Sable	12		5	5		
Springbok	15	20			30	30
Tsessebe	12		5	5		
Waterbuck	12		10	10		
Wildebeest (black)	12	45				
Wildebeest (blue)	12		70	60	30	30
Mixed feeders		**28%**	**25%**	**30%**	**20%**	**35%**
Duiker	6	2	3	3	3	3
Eland	12	95	10	14	54	92
Elephant	12		40	35		
Impala	15		30	35	30	
Nyala	12		5			
Ostrich	6		4	5	5	5
Reedbuck (mountain)	8	3	3	3	3	
Warthog	12		5	5	5	
Browsers		**2%**	**20%**	**20%**	**5%**	**3%**
Bushbuck	8		3	3		
Giraffe	8		60	50	30	
Klipspringer	4	5	1	1	5	5
Kudu	12	80	20	30	40	90
Rhebuck (grey)	8	10	3	3	5	
Rhino (black)	5		10	10	15	
Steenbok	5	5	3	3	5	5

*LSU: large stock unit.

Appendix 1B Minimum herd size and relative distribution of animal species per ecological region for smaller farms (ABSA, 2003)

		Relative distribution of animal species as a % of LSU*				
Animal species	**Min. social herd size**	**Grassland**	**Lowveld**	**Bushveld**	**Kalahari**	**Karoo**
Low selective grazers		20%	25%	20%	10%	2%
Buffalo	15		50			
Zebra (Burchell)	5	100	50	100		
Zebra (Cape mountain)	10				100	100
High selective grazers		50%	30%	30%	65%	60%
Blesbok	12	20				
Gemsbok	12				30	30
Red hartebeest	12	10		10	10	10
Reedbuck	8	5	5	5		
Springbok	15	20			30	30
Tsessebe	12		15	15		
Waterbuck	12		20	20		
Wildebeest (black)	12	45				
Wildebeest (blue)	12		60	50	30	30
Mixed feeders		28%	25%	30%	20%	35%
Duiker	6	2	2	2	2	3
Eland	12	95			43	92
Impala	15		60	70	25	
Nyala	12		10			
Ostrich	6		10	10	10	5
Reedbuck (mountain)	8	3	3	3	5	
Warthog	12		15	15	15	
Browsers		2%	20%	20%	5%	3%
Bushbuck	8		5	5		
Giraffe	8		55	50		
Klipspringer	4	15	2	2	5	10
Kudu	12		30	35	85	
Rhebuck (grey)	8	45	5	5		
Steenbok	5	40	3	3	10	90

*LSU: large stock unit.

Appendix 2A Breakdown of animal species, energy requirements, diet characteristics, intake and annual enteric methane emissions

Animal Species	Animal characteristics		LSU	Diet characteristics		Intake (kg DM/day)	Intake (%/LW)	CH_4 kg/h/year
	Weight (kg)	ME requirements (MJ/day)		Diet DE%	ME MJ/kg			
Elephant								
Calf (5 years)	850	84.8	1.13	55	8.3	10.2	1.2	23.9
Cow, dry (15 years)	1850	285	3.80	55	8.3	34.3	1.9	80.4
Cow, dry (50 years)	3300	291	3.88	55	8.3	35.1	1.1	82.1
Cow with calf (15 years)	1850	362	4.83	55	8.3	43.6	2.4	102.1
Cow with calf (50 years)	3300	375	5.00	55	8.3	45.2	1.4	105.8
Bull (15 years)	2200	303	4.04	55	8.3	36.5	1.7	85.5
Bull (50 years)	3700	310	4.13	55	8.3	37.3	1.0	87.5
Average	2435.7	287.3	3.83	55	8.3	34.6	1.4	81.0
Giraffe								
Calf (9 months)	390	57.8	0.77	65	9.81	5.9	1.5	63.8
Cow, dry (5 years)	770	111.0	1.48	65	9.81	11.3	1.5	132.9
Cow, dry (10 years)	850	101.0	1.35	65	9.81	10.3	1.2	119.9
Cow with calf (5 years)	770	139.0	1.85	65	9.81	14.2	1.8	169.3
Cow with calf (10 years)	850	130.0	1.73	65	9.81	13.3	1.6	157.6
Bull (5 years)	960	126.0	1.68	65	9.81	12.8	1.3	152.4
Bull (6 years)	1190	127.0	1.69	65	9.81	12.9	1.1	153.7
Average	825.7	113.1	1.51	65	9.81	11.5	1.4	135.6
Eland								
Calf (8 months)	200	38.9	0.52	65	9.81	4.0	2.0	39.3
Cow dry (3 years)	460	75.5	1.01	65	9.81	7.7	1.7	86.8
Cow dry (6 years)	500	72.1	0.96	65	9.81	7.3	1.5	82.4
Cow with calf (3 years)	460	96.6	1.29	65	9.81	9.8	2.1	114.2
Cow with calf (6 years)	500	87.1	1.16	65	9.81	8.9	1.8	101.9
Bull (3 years)	760	99.5	1.33	65	9.81	10.1	1.3	118.0
Bull (6 years)	815	96.0	1.28	65	9.81	9.8	1.2	113.4
Average	528	80.8	1.1	65	9.81	8.2	1.6	93.7

LSU: large stock unit; ME: metabolizable energy; DE: digestibility; DM: dry matter; LW: liveweight; CH_4: methane; kg/h/year = kg/head/year.

Appendix 2B Breakdown of animal species, energy requirements, diet characteristics, intake and annual enteric methane emissions

Animal species	Animal characteristics		LSU	Diet characteristics		Intake(kg DM/day)	Intake (%/ LW)	CH_4 (kg/h/year)
	Weight (kg)	ME requirements (MJ/day)		Diet DE%	ME (MJ/kg)			
Buffalo								
Calf (8 months)	145	31.8	0.42	55	8.3	3.8	2.6	37.6
Cow dry (4 years)	460	79.1	1.05	55	8.3	9.5	2.1	110.2
Cow dry (10 years)	530	76.4	1.02	55	8.3	9.2	1.7	106.0
Cow with calf (4 years)	460	101.0	1.35	55	8.3	12.2	2.6	143.2
Cow with calf (10 years)	530	99.3	1.32	55	8.3	12.0	2.3	141.2
Bull (4 years)	500	89.6	1.19	55	8.3	10.8	2.2	126.3
Bull (10 years)	640	87.7	1.17	55	8.3	10.6	1.7	123.4
Average	466.4	80.7	1.08	55	8.3	9.7	2.1	112.6
Zebra								
Foal (5 months)	95	24.6	0.33	55	8.3	3.0	3.1	6.9
Mare dry (4 years)	270	48.9	0.65	55	8.3	5.9	2.2	13.8
Mare dry (7 years)	290	45.0	0.60	55	8.3	5.4	1.9	12.7
Mare with foal (4 years)	270	61.0	0.81	55	8.3	7.3	2.7	17.2
Mare with foal (7 years)	290	58.9	0.79	55	8.3	7.1	2.4	16.6
Stallion (4 years)	310	54.0	0.72	55	8.3	6.5	2.1	15.2
Stallion (7 years)	335	52.1	0.69	55	8.3	6.3	1.9	14.7
Average	265.7	49.2	0.66	55	8.3	5.9	2.2	13.9
Kudu								
Calf (6 months)	55	15.8	0.21	65	9.81	1.6	2.9	9.3
Cow dry (3 years)	125	27.9	0.37	65	9.81	2.8	2.3	25.0
Cow dry (5 years)	160	29.8	0.40	65	9.81	3.0	1.9	27.5
Cow with calf (3 years)	125	34.9	0.47	65	9.81	3.6	2.8	34.1
Cow with calf (5 years)	160	38.7	0.52	65	9.81	3.9	2.5	39.0
Bull (3 years)	220	42.1	0.56	65	9.81	4.3	2.0	43.4
Bull (5 years)	240	39.9	0.53	65	9.81	4.1	1.7	40.6
Average	155	32.7	0.44	65	9.81	3.3	2.2	31.3

LSU: large stock unit; ME: metabolizable energy; DE: digestibility; DM: dry matter; LW: liveweight; CH_4: methane; kg/h/year = kg/head/year.

Appendix 2C Breakdown of animal species, energy requirements, diet characteristics, intake and annual enteric methane emissions

Animal species	Animal characteristics		LSU	Diet characteristics		Intake(kg DM/day)	Intake (%/LW)	CH_4 (kg/h/day)
	Weight (kg)	ME requirements (MJ/day)		Diet DE%	ME MJ/kg			
Waterbuck								
Lamb (5 months)	47	15.0	0.20	55	8.3	1.8	3.8	11.8
Ewe dry (3 years)	130	27.6	0.37	55	8.3	3.3	2.6	31.1
Ewe dry (5 years)	160	28.1	0.37	55	8.3	3.4	2.1	31.9
Ewe with lamb (3 years)	130	34.6	0.46	55	8.3	4.2	3.2	41.9
Ewe with lamb (5 years)	160	36.6	0.49	55	8.3	4.4	2.8	44.9
Ram (3 years)	195	37.3	0.50	55	8.3	4.5	2.3	46.0
Ram (5 years)	225	35.6	0.47	55	8.3	4.3	1.9	43.4
Average	149.6	30.7	0.41	55	8.3	3.7	2.5	35.9
Blue wildebeest								
Calf (4 months)	51	15.6	0.21	75	11.32	1.4	2.7	6.3
Cow dry (3 years)	145	29.8	0.40	75	11.32	2.6	1.8	22.3
Cow dry (5 years)	160	29.4	0.39	75	11.32	2.6	1.6	21.8
Cow with calf (3 years)	145	37.3	0.50	75	11.32	3.3	2.3	30.7
Cow with calf (5 years)	160	38.3	0.51	75	11.32	3.4	2.1	31.9
Bull (3 years)	195	37.2	0.50	75	11.32	3.3	1.7	30.6
Bull (5 years)	215	36.3	0.48	75	11.32	3.2	1.5	29.6
Average	153	32.0	0.43	75	11.32	2.8	1.8	24.8
Black wildebeest								
Calf (4 months)	40	12.5	0.17	75	11.32	1.1	2.8	8.2
Cow dry (3 years)	105	20.3	0.27	75	11.32	1.8	1.7	12.9
Cow dry (5 years)	115	21.6	0.29	75	11.32	1.9	1.7	13.7
Cow with calf (3 years)	105	25.4	0.34	75	11.32	2.2	2.1	15.7
Cow with calf (5 years)	115	28.2	0.38	75	11.32	2.5	2.2	17.7
Bull (3 years)	125	25.1	0.33	75	11.32	2.2	1.8	15.8
Bull (5 years)	135	25.3	0.34	75	11.32	2.2	1.7	15.9
Average	105.7	22.6	0.30	75	11.32	2.0	1.9	14.3

LSU: large stock unit; ME: metabolizable energy; DE: digestibility; DM: dry matter; LW: liveweight; CH_4:methane; kg/h/year = kg/head/year.

Appendix 2D Breakdown of animal species, energy requirements, diet characteristics, intake and annual enteric methane emissions

Animal species	Animal characteristics		LSU	Diet characteristics		Intake (kg DM/day)	Intake (%/LW)	CH_4 (kg/h/day)
	Weight (kg)	ME requirements (MJ/day)		Diet DE%	ME MJ/kg			
Tsessebe								
Lamb (5 months)	38	12.2	0.16	65	11.32	1.1	2.8	8.0
Ewe dry (3 years)	104	19.6	0.26	65	11.32	1.7	1.7	12.5
Ewe dry (5 years)	113	20.9	0.28	65	11.32	1.8	1.6	13.3
Ewe with lamb (3 years)	104	24.6	0.33	65	11.32	2.2	2.1	15.5
Ewe with lamb (5 years)	113	27.2	0.36	65	11.32	2.4	2.1	17.1
Ram (3 years)	126	24.2	0.32	65	11.32	2.1	1.7	15.3
Ram (5 years)	138	24.2	0.32	65	11.32	2.1	1.5	15.3
Average	105.1	21.8	0.29	65	11.32	1.9	1.8	13.8
Blesbok								
Lamb (5 months)	23	7.6	0.10	75	11.32	0.7	2.9	5.2
Ewe dry (3 years)	60	12.3	0.16	75	11.32	1.1	1.8	8.0
Ewe dry (5 years)	67	14.7	0.20	75	11.32	1.3	1.9	9.5
Ewe with lamb (3 years)	60	15.4	0.21	75	11.32	1.4	2.3	9.9
Ewe with lamb (5 years)	67	19.1	0.25	75	11.32	1.7	2.5	12.2
Ram (3 years)	73	14.3	0.19	75	11.32	1.3	1.7	9.3
Ram (5 years)	81	14.8	0.20	75	11.32	1.3	1.6	9.6
Average	61.6	14.0	0.19	75	11.32	1.2	2.0	9.1
Warthog								
Piglet (3 months)	13	6.2	0.08	75	11.32	0.5	4.2	3.6
Sow dry (2 years)	59	15.0	0.20	75	11.32	1.3	2.2	1.9
Sow dry (3 years)	65	13.9	0.19	75	11.32	1.2	1.9	1.6
Sow with litter (2 years)	59	21.1	0.28	75	11.32	1.9	3.2	2.7
Sow with litter (3 years)	65	20.1	0.27	75	11.32	1.8	2.7	2.3
Boar (2 years)	74	18.4	0.25	75	11.32	1.6	2.2	1.9
Boar (3 years)	80	16.2	0.22	75	11.32	1.4	1.8	1.5
Average	59.3	15.8	0.21	75	11.32	1.4	2.4	2.2

LSU: large stock unit; ME: metabolizable energy; DE: digestibility; DM: dry matter; LW: liveweight; CH_4: methane; kg/h/year = kg/head/year.

Appendix 2E Breakdown of animal species, energy requirements, diet characteristics, intake and annual enteric methane emissions

Animal species	Animal characteristics		LSU	Diet characteristics		Intake (kg DM/day)	Intake (%/LW)	CH_4 (kg/h/day)
	Weight (kg)	ME requirements (MJ/day)		Diet DE%	ME MJ/day			
Impala								
Lamb (4 months)	19	5.8	0.08	75	11.32	0.5	2.7	4.1
Ewe dry (2 years)	37	10.8	0.14	75	11.32	1.0	2.6	7.1
Ewe dry (4 years)	45	10.2	0.14	75	11.32	0.9	2.0	6.8
Ewe with lamb (2 years)	37	14.0	0.19	75	11.32	1.2	3.3	9.1
Ewe with lamb (4 years)	45	13.9	0.19	75	11.32	1.2	2.7	9.0
Ram (2 years)	51	11.9	0.16	75	11.32	1.1	2.1	7.8
Ram (4 years)	60	12.2	0.16	75	11.32	1.1	1.8	8.0
Average	42	11.3	0.15	75	11.32	1.0	2.4	7.4
Springbok								
Lamb (2.5 months)	12	3.2	0.04	75	11.32	0.3	2.3	2.5
Ewe dry (18 months)	27	6.3	0.08	75	11.32	0.6	2.1	4.4
Ewe dry (3 years)	31	7.0	0.09	75	11.32	0.6	2.0	4.8
Ewe with lamb (18 months)	27	7.9	0.10	75	11.32	0.7	2.6	5.3
Ewe with lamb (3 years)	31	9.1	0.12	75	11.32	0.8	2.6	6.1
Ram (18 months)	30	7.1	0.09	75	11.32	0.6	2.1	4.9
Ram (3 years)	36	7.4	0.10	75	11.32	0.7	1.8	5.0
Average	27.7	6.8	0.09	75	11.32	0.6	2.2	4.7

LSU: large stock unit; ME: metabolizable energy; DE: digestibility; DM: dry matter; LW: liveweight; CH_4: methane; kg/h/year = kg/head/year.