

## Case Report

# Enteric Methane Emissions Estimate for Livestock in South Africa for 1990–2014

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Academic Editor: Robert W. Talbot

Received: 12 January 2017; Accepted: 28 March 2017; Published: 16 May 2017

**Abstract:** Methane (CH<sub>4</sub>) from enteric fermentation is one of the main anthropogenic greenhouse gas (GHG) emissions in South Africa. Livestock population data from 1990 to 2014 and emission factors were utilized in estimating CH<sub>4</sub> emissions as per the 2006 IPCC (Intergovernmental Panel on Climate Change) guidelines. CH<sub>4</sub> emissions originating from country-specific emission factors were compared with those calculated using IPCC default emission factors. Trends in emissions were then determined using the Man-Kendall trend test at the 5% significance level. The results showed annual total enteric CH<sub>4</sub> emissions exceeding 1171.56 Gg (in 1995) with an average (1990 to 2014) of 1227.96 Gg. Non-dairy cattle are the highest emitters with an average of 873.07 Gg (71.10%) while sheep are the second highest with 227.61 Gg (18.54%). Other contributors are dairy cattle, goats, horses, pigs and donkeys with an average (percentage contribution) of 85.94 Gg (7.00%), 32.06 Gg (2.61%), 4.86 Gg (0.40%), 2.77 Gg (0.23%) and 1.65 Gg (0.13%), respectively. The trend analysis revealed positive trends for all the livestock categories, except sheep and goats which showed negative trends, consequently balancing out. The results obtained for the year 2014 were 37% higher than the enteric CH<sub>4</sub> emissions in 1990, 1994 and 2000 inventories and the emissions estimated entirely from IPCC default emission factors. This demonstrates the need for the development of Tier 2 emission factors for key category sectors such as cattle and sheep in South Africa. To fully adhere to the principles of GHG inventory accounting, there has to be total livestock inclusivity and major improvements in activity data collection.

**Keywords:** activity data; emission factors; IPCC guidelines; GHG inventory

## 1. Introduction

Livestock play an important role in providing food, employment, income, draft power and nutritional security to the societies all over the world [1,2]. On the other hand, livestock activities can result in significant impact on the environment; this impact is growing and changing rapidly due to global pressures associated with, among others, population growth and urbanization [3,4]. Human consumption and utilization of meat and other products from livestock are a major source of climate change resulting in 14%–18% of global anthropogenic greenhouse gas (GHG) emissions [3,5]. However, Goodland and Anhang [6] suggested that estimations of the global GHG contribution from domestic livestock are underestimated and this could rise up to 50% of the total GHG emissions. The contribution of GHG emissions from livestock is expected to increase in the future due to an escalating demand for food, meat and milk consumption [7]. Livestock farming contributes directly and indirectly to

GHG emissions through a number of procedures, i.e., enteric fermentation in domestic livestock and livestock manure management [8].

Methane ( $\text{CH}_4$ ) is the main GHG produced from agricultural livestock production, contributing about 18% of the global GHG emissions and as much as 37% of anthropogenic  $\text{CH}_4$  [9–11]. Enteric fermentation from livestock is the main contributor of livestock  $\text{CH}_4$  emissions accounting for 32%–40% of total agricultural emissions [12]. Enteric fermentation is a result of the microbiological process which breaks down cellulose and other macromolecules in the rumen and large intestines into simple molecules for absorption into the bloodstream, generating  $\text{CH}_4$  that is expelled mostly through the mouth and nose [9,13,14]. Kebreab et al. [15] further states that enteric  $\text{CH}_4$  emissions represent a loss of energy of 2%–12% of the gross energy intake. According to Smith et al. [12] and Patra [16], enteric emissions have been increasing globally by 0.70% from 1990 to 2010 and are projected to rise in the future.

In South Africa, livestock production accounts for about 70% of the agricultural land use due to extensive areas of marginal soils and low rainfall [17,18]. Livestock production varies substantially with numbers, breeds and species according to grazing, environment and production systems (commercial, small-scale or communal) [17,19]. These differences in the management of livestock in the country are also reflected in the impact on GHG emissions from the livestock sector. South Africa prepared its first GHG inventory with the base years 1990 and 1994 using the 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines and a combination of Tier 1 and Tier 2 approaches for enteric fermentation [20]. In 2004, the South African Department of Environmental Affairs (DEA) published the 2000 inventory which was based on Tier 1 methodology [21]. In 2010, the South African Department of Agriculture, Forestry and Fisheries (DAFF) estimated the country's enteric fermentation emissions for 2004 with a Tier 2 approach for dairy and non-dairy cattle [22]. There has been further work post-2005 that estimated emissions from enteric fermentation using country-specific activity data [23,24].

In this study, enteric  $\text{CH}_4$  emissions from 1990 to 2014 were calculated in accordance with the 2006 IPCC guidelines [8] for national GHG inventories utilizing both country-specific emission factors and IPCC default emission factors.

## 2. Materials and Methods

Estimation of  $\text{CH}_4$  emissions from enteric fermentation requires a specific procedure. According to IPCC (2006), three main steps need to be followed: (1) collection of livestock population data per subcategories of animals, (2) estimation of emissions factors for each subgroup or utilization of default emissions factors, and (3) multiplication of emissions factors by their corresponding populations. The animal types of significance to South Africa are cattle, sheep, goats, horses, donkeys, mules and pigs. The main subcategories for cattle were dairy cattle, commercial beef cattle and small-scale cattle farming.

### 2.1. Collection of Population Data

Animal population data on cattle, sheep, goats and pigs for South Africa were obtained from agricultural census and data recorded by DAFF Agricultural Statistics Directorate [25]. The data on horses, donkeys and mules were obtained from the Food and Agriculture Organization (FAO) Statistics [26]. Table 1 shows the population data for all the years. Data on horses, donkeys and mules for the year 2014 was not available so the values presented were estimated from the increase in annual numbers from 2012 to 2013 in the FAO Statistics.

**Table 1.** Annual animal population data from 1990 to 2014 in South Africa.

Year	Animal Category						
	Dairy Cows	Non-Dairy Cattle	Sheep	Goats	Horses	Donkeys and Mules	Pigs
	(1,000,000)						
1990	0.770	13.265	33.065	6.971	0.230	0.164	2.658
1991	0.890	13.423	31.717	6.650	0.230	0.164	2.842
1992	0.770	13.579	30.534	6.482	0.230	0.164	2.746
1993	0.820	13.126	28.756	6.356	0.235	0.164	2.783
1994	0.770	12.481	28.937	6.534	0.240	0.164	2.618
1995	0.820	12.383	28.567	6.566	0.245	0.164	2.569
1996	0.820	12.800	28.652	6.603	0.250	0.164	2.801
1997	0.790	13.215	28.096	6.591	0.255	0.164	2.782
1998	0.790	13.509	28.165	6.557	0.260	0.164	2.764
1999	0.760	13.668	27.755	6.192	0.258	0.164	2.780
2000	0.990	13.372	26.741	6.346	0.270	0.164	2.717
2001	0.990	13.152	26.411	6.550	0.270	0.164	2.607
2002	0.850	13.353	25.577	6.599	0.270	0.164	2.716
2003	0.790	13.531	25.577	6.396	0.270	0.164	2.700
2004	0.770	13.471	25.356	6.388	0.270	0.164	2.726
2005	0.820	13.458	25.289	6.385	0.270	0.164	2.727
2006	0.800	13.549	24.956	6.407	0.280	0.164	2.764
2007	0.790	13.981	25.031	6.265	0.290	0.165	2.897
2008	0.980	13.700	25.005	6.529	0.298	0.165	2.832
2009	1.000	13.607	24.989	6.357	0.300	0.165	2.801
2010	1.000	13.539	24.501	6.274	0.300	0.166	2.828
2011	0.970	13.562	24.303	6.165	0.305	0.167	2.881
2012	0.930	13.802	24.391	6.142	0.308	0.167	2.901
2013	0.990	13.767	24.528	6.028	0.310	0.171	2.937
2014	0.950	13.884	24.122	5.971	0.312	0.174	2.980

## 2.2. Emission Factor (EF)

Emission factors shown in Table 2 were obtained from the agricultural emissions report by Moeletsi et al. [27] in accordance with the IPCC reporting categories. The key source categories analysis by DEA [21,28] shows that emissions from cattle and sheep were found to be significant. Thus, country-specific emission factors were used for those animal categories, while IPCC default EF (Emission Factor) values were utilized for goats, horses, donkeys and mules, and pigs because of their insignificance. Country-specific emission factors were calculated using data collected from the farms which was complemented by expert opinion using a Tier 2 approach [27]. Dairy cattle data was collected for the three main dairy management systems, namely: total mixing ration (TMR), pasture based system and mixture of TMR and pasture systems resulting to individual emissions factors of 83.70 kg CH<sub>4</sub>/head/year, 112.36 kg CH<sub>4</sub>/head/year and 108.53 kg CH<sub>4</sub>/head/year respectively [27]. Non-dairy cattle were subdivided into commercial cattle, subsistence cattle and feedlot cattle and these categories were further subdivided according to calves, heifers, bulls and oxen. Emissions factors for all the subcategories of non-dairy cattle ranged from 31.70 kg CH<sub>4</sub>/head/year to 106.70 kg CH<sub>4</sub>/head/year with a weighted average of 65.13 kg CH<sub>4</sub>/head/year [27]. In their report, Moeletsi et al. [27] categorized sheep into wool, non-wool and subsistence sheep with further subcategories of lamb, ewe, rams and replacements sheep. Sheep emission factors ranged from 4.00 kg CH<sub>4</sub>/head/year to 13.30 kg CH<sub>4</sub>/head/year with a weighted average of 8.48 kg CH<sub>4</sub>/head/year based on annual populations. The emission factors were assumed to be constant in all the years.

**Table 2.** Enteric methane emission factors for IPCC (Intergovernmental Panel on Climate Change) livestock categories [8,27].

Livestock Type	Emission Factor (kg/head/year)	
	IPCC Default Values	Country-Specific Values
Dairy Cows	45.00	99.37
Non-Dairy Cattle	31.00	65.12
Sheep	5.00	8.48
Goats	5.00	-
Horses	18.00	-
Donkeys and Mules	10.00	-
Pigs	1.00	-

–: Country specific emissions not used.

### 2.3. Emissions Estimate

The IPCC has developed methodologies for estimation of national GHG emissions [8]. Calculation of the emissions is normally approached through the utilization of activity data (magnitude of the anthropogenic act causing emissions) and the emission factor (coefficient quantifying the strength of the activity) using Equation (1).

$$\text{Emissions} = \text{Activity data} \times \text{Emission factor} \quad (1)$$

Enteric CH<sub>4</sub> emissions were obtained for each of the years from 1990 to 2014 and then compared to the previous inventory values and emissions calculated using IPCC default EF.

### 2.4. Determination of Trends

To determine evolution of enteric CH<sub>4</sub> emissions over the years, the Mann-Kendall trend test of the XLSTAT statistical software (2015 version, Addinsoft, New York, NY, USA) was utilized for all the animal categories and sub-categories. The trend test was based on the following deductions:

**H<sub>0</sub>:** There is no trend in the data (Null Hypothesis);

**H<sub>1</sub>:** There is a trend in the data (Alternative Hypothesis).

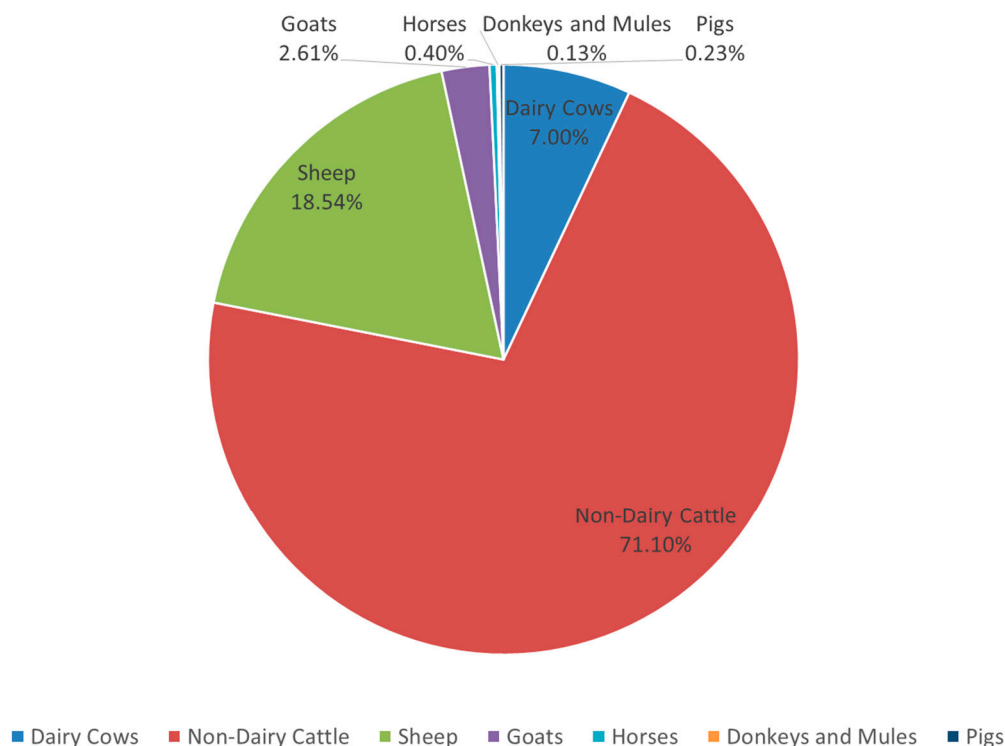
The null hypothesis is true when the calculated *p*-value is more than  $\alpha$  (significance level) whilst the alternative hypothesis is true when the *p*-value is less than  $\alpha$ .

## 3. Results and Discussion

### 3.1. Enteric Emissions from 1990 to 2014 Using Country-Specific Emission Factors

Annual total CH<sub>4</sub> emissions from all the animals were calculated as a summation of the individual emissions from each animal category [8]. As shown in Table S1, the total CH<sub>4</sub> emissions from enteric fermentation ranged from 1171.56 Gg (in 1995) to 1273.38 Gg (in 1991) with an average of 1227.96 Gg and a standard deviation (coefficient of variation) of 24 Gg (2%). Non-dairy cattle in South Africa contribute far more than any other IPCC animal categories with an average of 873.07 Gg CH<sub>4</sub> per year, contributing around 71.10% of the total enteric emissions in the country (Figure 1). The main reason for this is the high population (over 13 million) of this category coupled with a relatively high EF. Sheep farming is the second highest emitter with around 227.61 Gg amounting to over 18% of the total emissions mainly because of the high population exceeding 24 million annually. The third highest contributor is dairy cattle with emissions exceeding 85.94 Gg (7% of total emissions) annually. Even though the annual population of this animal subcategory is low compared to other categories, its emission intensity (per head) of close to 100 kg CH<sub>4</sub> per year is the causal factor. Other IPCC livestock categories contribute individually less than 3% with goats, horses, pigs and donkeys and mules having

average emissions (percentage of total emissions) of 32.06 Gg (2.61%), 4.86 Gg (0.4%), 2.77 Gg (0.23%) and 1.65 Gg (0.13%), respectively. The results of DEA [29] on 2010 enteric CH<sub>4</sub> emissions had the following proportional representation for the main contributors: non-dairy cattle (69%), sheep (14%), dairy cattle (13%) and goats (3%). The main difference is due to a relatively high EF, exceeding 120 kg CH<sub>4</sub> per head, which was used to calculate dairy cattle emissions in the DEA report while the EF utilized in the present study was 99.4 kg CH<sub>4</sub> per head based on aggregated EFs from three different production systems practiced in South Africa [27,28].



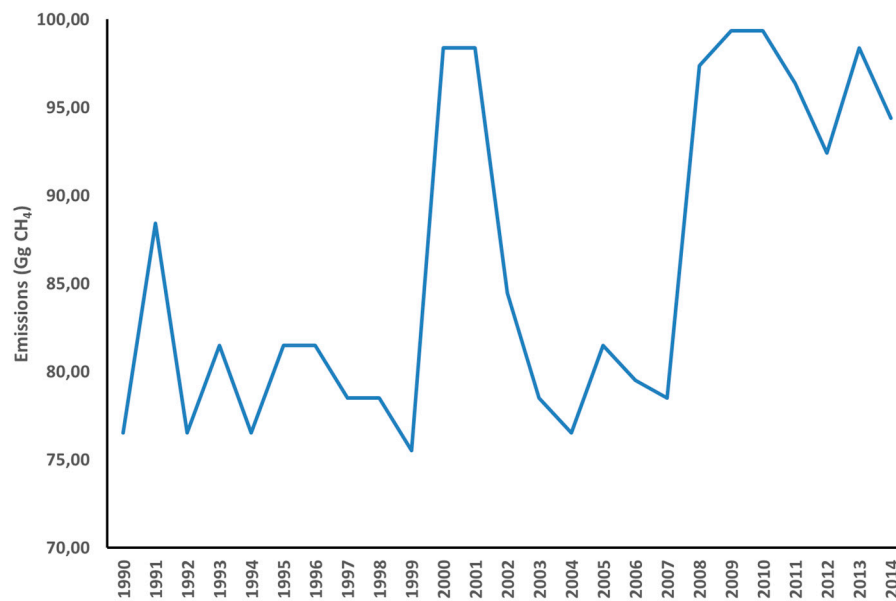
**Figure 1.** Proportional representations of different animal categories on enteric methane emissions from 1990–2014.

### 3.2. Enteric Emissions Using IPCC Default Emission Factors

Compared with emissions obtained using country-specific EFs, estimated CH<sub>4</sub> emissions from enteric fermentation for the period 1990 to 2014 drop by over 48% when utilizing 2006 IPCC default emission factors for all the animals (Table 3; Figures 2–7; Table S1). The proportional representation of the different livestock also changes slightly with non-dairy cattle, sheep, dairy cattle and goats having 66%, 21%, 6% and 5%, respectively. The other livestock categories each still contribute less than 1% of the total emissions. Parta [16] estimated enteric CH<sub>4</sub> emissions using Tier 1 methodology globally and in India, and obtained percentage animal contributions which slightly differed from those of South Africa due to the animal type composition. In developing countries such as South Africa where agriculture is mostly commercial, default IPCC EFs will tend to underestimate emissions due to the utilization of averaged activity data that includes data from non-intensive agricultural countries [8]. The IPCC default values can overestimate emissions of some sections of the livestock population in other parts of the world, especially in developed countries [30]. As a result of these variations, IPCC encourages the development of country-specific emission factors to enable close estimation of the country's emissions [31].

**Table 3.** South African average enteric methane emissions from 1990 to 2014 using 2006 IPCC default factors.

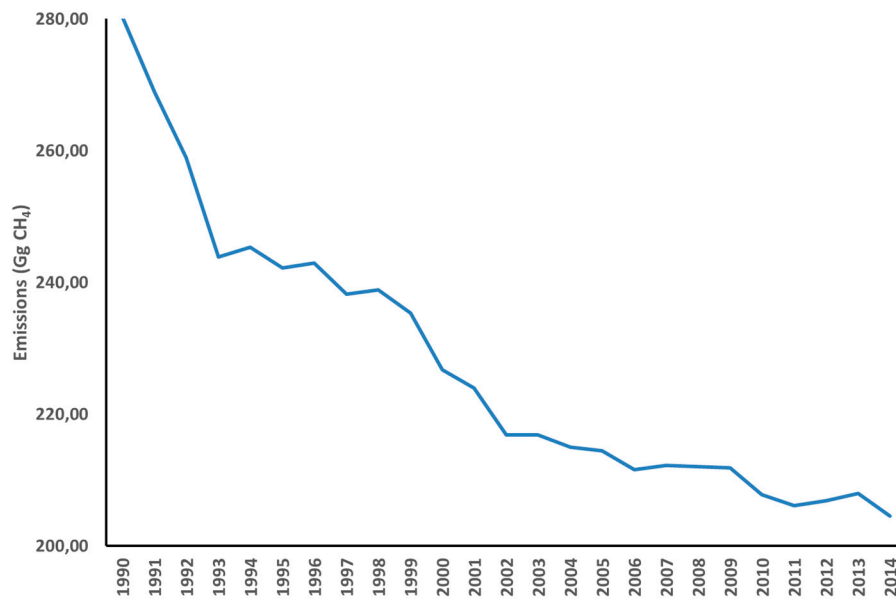
Animal Category							Total Emissions
Dairy Cows	Non-Dairy Cattle	Sheep	Goats	Horses	Donkeys and Mules	Pigs	
(Gg CH <sub>4</sub> per year)							
39.78	415.62	134.20	32.06	4.86	1.65	2.77	630.95



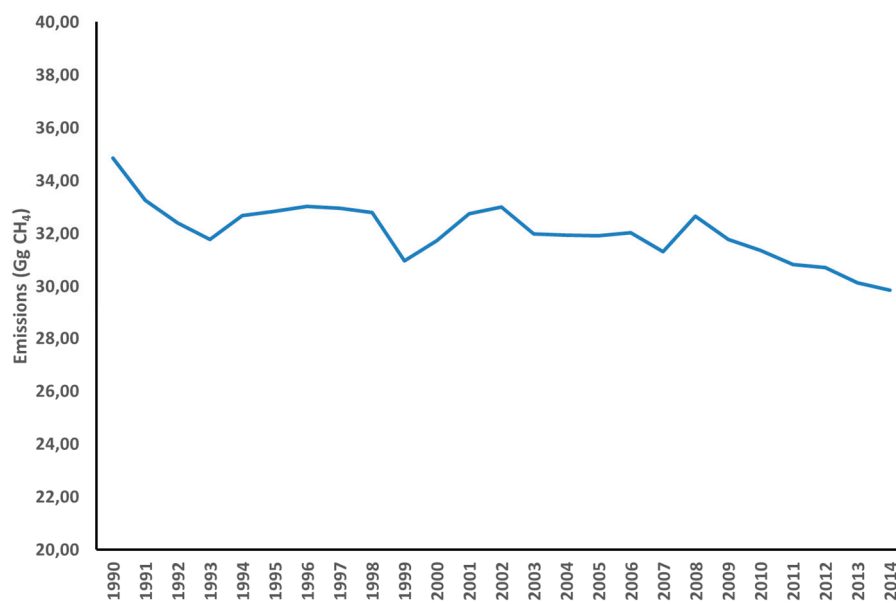
**Figure 2.** Enteric emissions (Gg CH<sub>4</sub>) for South African dairy cattle from 1990 to 2014.



**Figure 3.** Enteric emissions (Gg CH<sub>4</sub>) for South African non-dairy cattle from 1990 to 2014.

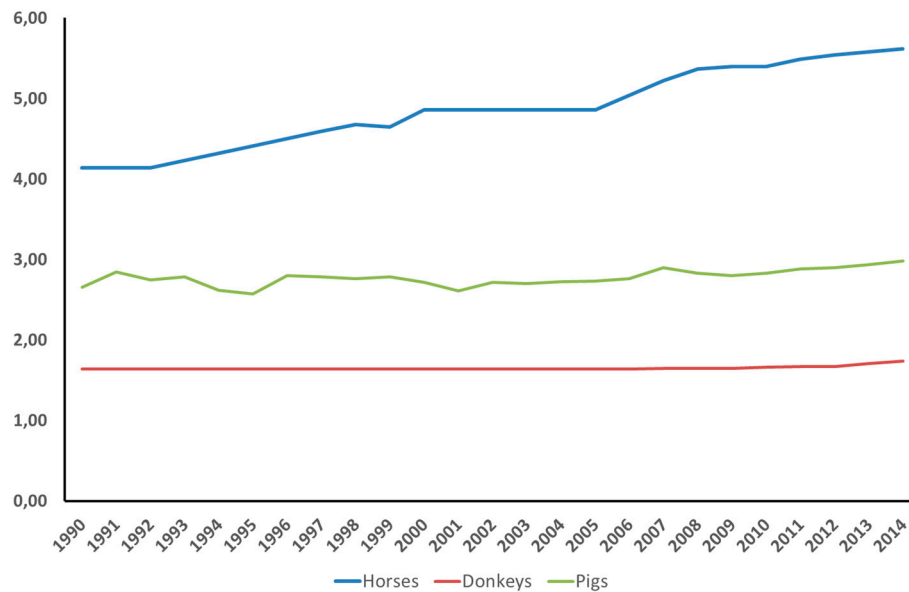


**Figure 4.** Enteric emissions (Gg CH<sub>4</sub>) for South African sheep from 1990 to 2014.

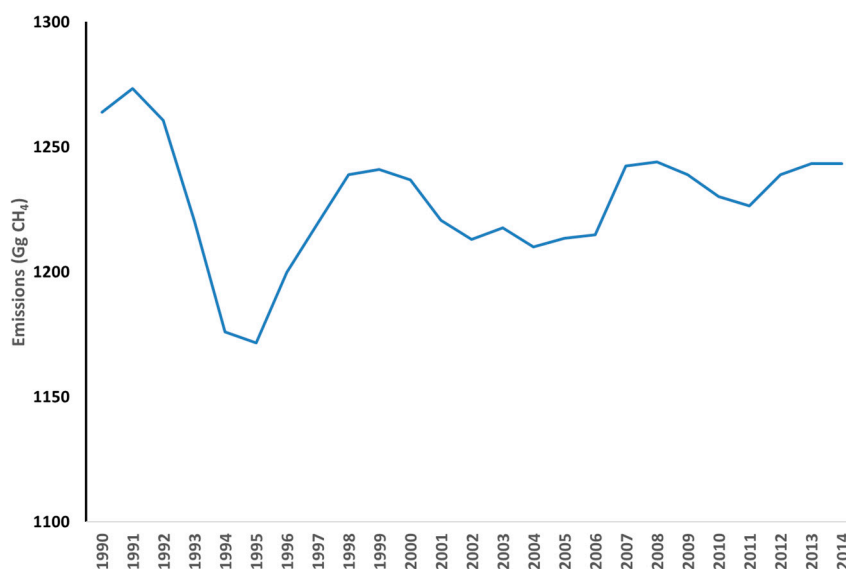


**Figure 5.** Enteric emissions (Gg CH<sub>4</sub>) for South African goats from 1990 to 2014.





**Figure 6.** Enteric emissions (Gg CH<sub>4</sub>) for South African horses, donkeys and pigs from 1990 to 2014.



**Figure 7.** Total enteric emissions (Gg CH<sub>4</sub>) for South African animals (dairy cattle, non-dairy cattle, horses, donkeys and pigs) from 1990 to 2014.

### 3.3. Comparison with Previous Inventories

Total enteric CH<sub>4</sub> emissions attained for the previous inventories (1990, 2000, 2004, and 2010) were 916.55 Gg [20], 903.23 Gg [28], 1183.56 Gg [22] and 1172.95 Gg [29]. The estimated emissions for this study are higher by 37% (1990), 37% (1994), 37% (2000), 2% (2004) and 5% (2010). The main dissimilarity with the first two inventories was due to the major differences in EFs. EFs for dairy cattle and non-dairy cattle are found to be higher than those obtained in 1990 and 2000 by 20 kg/head/year and 15 kg/head/year, respectively. In 1990 and 2000, the default EF for sheep (5 kg/head/year) was applied as compared with the 8.48 kg/head/year for sheep (Tier 2). There was also a decrease in the total number of sheep and goats (37.2 million for 1990; 27.52 million for 2012) while the number of cattle slightly increased (13.5 million for 1990; 14.715 million for 2012). The slight increase in emissions as compared with the 2004 and 2010 inventories was caused by a combination of factors including: the addition of feedlot sheep in the 2012 emissions; the increase of feedlot cattle from 420,000 to 815,000



as recorded by abattoir slaughterings [25]—numbers still slightly less than the 1.1 million reported in 1990; and the default emission factors utilized for sheep in 2004.

### 3.4. Trend Analysis

The dairy cattle, non-dairy cattle, horses, pigs and donkeys showed increasing trends as depicted by positive Kendall's Tau values (Table 4), with an annual rate of increase of 0.750 Gg, 2.191 Gg, 0.065 Gg, 0.009 Gg and 0.002 Gg, respectively. In contrast, the sheep and goat farming emissions showed decreasing trends (i.e., negative Kendall's Tau values) with the annual rates of  $-2.671$  Gg and  $-0.114$  Gg, respectively. The total enteric CH<sub>4</sub> emissions show a slight bias to an increasing trend (as shown by a Kendall's Tau value of 0.1) which is not significant. It is thus concluded that total emissions do not have any trend, even though five of the livestock categories showed positive trends. The non-existence of an increasing trend in the total emissions is mainly the counter-balance of the high negative trend in sheep and goat farming emissions caused by their respective decreasing population [25].

**Table 4.** Trend analysis of South African enteric emissions from 1990 to 2014.

Statistics	Dairy Cows	Non-Dairy Cattle	Sheep	Goats	Horses	Donkeys and Mules	Pigs	Total
Kendall's Tau	0.367	0.547	−0.932	−0.587	0.961	0.772	0.433	0.100
p-value (two-tailed)	0.013	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.002	0.503
Alpha ( $\alpha$ )	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Decision	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Rejected	Accepted

### 3.5. Improvements in Estimation of Enteric Methane

The national GHG emissions inventory forms a good basis for government climate change and mitigation strategies [32]. Thus, the inventory has to be inclusive and needs to cover all the sources and sinks for it to be useful to government agencies. Due to the advancement of the game farm industry in South Africa, Du Toit et al. [33] attempted the estimation of the enteric emissions by using the carrying capacity of the game farms due to a lack of population data of game farm animals. However, the calculation of animal numbers based on one variable is not sufficient since the animal population is a factor of multiple variables. Thus, the inclusion of game farms in the national animal census by Statistics South Africa as well as agricultural statistics of DAFF would advance GHG inventory development in the country. Other animals such as donkeys and horses are also not part of the national census data and inclusion of these animals would also improve estimations of emissions significantly. FAO [34] encourages developing countries to utilize the FAOSTAT database to patch the country dataset. The FAOSTAT dataset is highly helpful but each country has the mandate to report the best estimates of GHG emissions and this requires effort to continually improve their methodologies and activity data to have a more comprehensive and complete GHG inventory [8].

In South Africa, the awarding of GHG inventory compilation work is undertaken through a tender process. This means that preparation of the GHG inventory is granted to different institutions based on the evaluation of their proposals. Lack of permanent hosting organizations promotes lack of continuity in approaches, resulting in different uses of emission factors and the inconsistent presentation of results [21,22,28,29]. According to FAO [34] and Ogle et al. [32], countries should have clear institutional arrangements for the compilation of GHG inventories. Assigned institutions will be able to improve on emission estimates as they will have a mandate to employ specialists for each of the sectors. South Africa can give responsibilities to relevant institutions in the country to concentrate on certain sectors and build on GHG emission systems, and that would assist in more efficient reporting to the United Nations Framework Convention on Climate Change, and the quality of the GHG inventories would improve as methods will be consistent with time. In these institutions, scientists would be able to embark on specialist fields to estimate country-specific emission factors that would enable the accurate estimation of emissions and the policy decision-makers would base their

arguments on reliable information. Consistent archiving of activity data and filling of gaps would also be improved if the same institutions could be used to compile the inventories. Reliable information can also help in the identification of proper responses in line with food security and economic development in the country [22].

#### 4. Conclusions

The study has shown that the South African total enteric methane emissions vary from year to year, with values ranging from 1171.56 to 1273.38 Gg per year. The main contributors are non-dairy cattle, sheep, dairy cattle and goats with approximately 71.10%, 18.54%, 7.00% and 2.61%, respectively. Other livestock (donkeys, horses and pigs) have a combined contribution of less than 1%. Tier 1 estimations for all the animals result in total average enteric emissions of 630.95 Gg per year which represents a 37% reduction in estimations, and hence the need for the development of country-specific emission factors. The trend analysis of the emissions from 1990 to 2014 showed significant contrasting trends in all the animals but the total emissions showed no trend. Based on the results of the study, improvement in the enteric fermentation estimation is recommended to account for all the domesticated animals. Adherence to the IPCC recommendations in setting appropriate institutional arrangements in undertaking of the GHG estimation for reporting to the United Nations Framework Convention on Climate Change is encouraged for improved approximations.

**Supplementary Materials:** The following are available online at [www.mdpi.com/2073-4433/8/4/69/s1](http://www.mdpi.com/2073-4433/8/4/69/s1). Table S1: South African enteric methane emissions from 1990 to 2014 using country-specific factors for cattle and sheep and IPCC default factors for all other animals.

**Acknowledgments:** The study was conducted with funding from the South African Department of Environmental Affairs. Thomas Fyfield of the Agricultural Research Council is thanked for editing this manuscript.

**Author Contributions:** Mokhele Moeletsi, Mphethe Tongwane and Mitsuru Tsubo were involved in the writing of manuscript, collection and analyses of data.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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