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Improving livestock GHG inventories in Africa

Which model to use?

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IMPROVING LIVESTOCK GHG INVENTORIES IN AFRICA
WHICH MODEL TO USE?

The Intergovernmental Panel on Climate Change (IPCC) recommends to use a more advanced (Tier 2) methods to quantify livestock GHG emissions when enteric fermentation from livestock is a significant source of national greenhouse gas (GHG) emissions. Enteric fermentation is a key category in many African countries' national GHG inventories, and several countries are now working on improving their national inventories for livestock. Countries can either use the IPCC Tier 2 model or a country-specific model. To date, Sub-Saharan African countries have used one of two models used to estimate enteric fermentation emissions in their national GHG inventories: the IPCC model (used in Benin, Ethiopia, Kenya and Namibia) and a model based on Australian equations used in South Africa's GHG inventory. As more countries consider adopting a Tier 2 method, the question arises: which model to use?

In this information brief, we compare emission factors (EFs) for 26 sub-categories of dairy cattle and 59 subcategories of beef ('other') cattle calculated using both the IPCC and South African models. The results show that there are systematic differences between the models and that each model has particular strengths and weaknesses (see Text Box).

THE IPCC AND SOUTH AFRICAN MODELS

The IPCC model is described in the 2006 IPCC Guidelines. The model predicts gross energy intake (GEI, MJ head-1 day-1) on the basis of animal performance and net energy requirements. To calculate the emission factor (EF), the two key variables are GEI and a methane conversion factor (Ym, % of GEI converted to methane):

EF = [GEI * (Ym/100) *365] / 55.65

IPCC (2006) proposed a default value of 6.5% for Ym, and the 2019 Refinement updated this to 7.0%. Other aspects of the IPCC model for cattle remain the same.

The South African inventory implemented two different models for dairy and beef cattle (du Toit et al. 2013). For dairy cattle, dry matter intake (DMI) is predicted following Minson & MacDonald (1987). GEI is calculated as DMI * 18.4 MJ kg-1 DMI. Methane yield (Y, % of GEI converted to methane) is calculated following Blaxter and Clapperton (1965) as a function of dry matter digestibility (DMD) and the level of DMI relative to maintenance requirements. The emission factor is then calculated as:

EF = Y/100 * GEI/55.22.

This model has the same key variables as the IPCC model, but both Y and GEI are calculated differently.

For beef cattle, DMI is also calculated using the Minson & MacDonald (1987) equations and the emission factor is then calculated using an equation from Kurihara et al. (1999):

EF = (34.9 * DMI – 30.8)/1000.

COMPARISON OF IPCC AND SOUTH AFRICAN ENTERIC FERMENTATION MODELS

For dairy cattle, the mean difference in emission factors was 11.0 kg CH4 head-1 day-1, which was 19% - 24% of the average EF estimated using each model.

For other cattle, the mean difference in emission factors was 3.9 kg CH4 head-1 day-1, which was 8% - 9% of the average EF estimated using each model.

Without direct measurements for comparison, it is only possible to indicate the relative bias of each model, but not the accuracy. Other strengths and weaknesses of each model include:

- There are existing estimates for the uncertainty of coefficients in the IPCC model, so it is easier to apply uncertainty analysis which is an essential element of GHG inventory compilation;
- For other (non-dairy) cattle, the South African model requires data on fewer variables, so it is much easier to apply in data-scarce countries; and
- The South African model for other cattle does not include a feed quality parameter, which limits the ability of this model to reflect the effect of feed-related mitigation options in the inventory.

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Table 1: Number of sub-categories assessed

Country	Dairy cattle	Other cattle
Benin	-	13 Somba breed 8 Borgou breed 10 Lagune breed
Ethiopia	4 sub-categories	7 pastoral/agro-pastoral 9 mixed crop-livestock
Kenya	3 intensive 3 semi-intensive	-
South Africa	8 TMR 8 pasture-based	6 commercial 6 communal
Total	**26**	**59**

MODEL COMPARISON

Both models were programmed in Excel and parameter values extracted from the original publications for South Africa (du Toit et al. 2013), Benin (Kouazounde et al. 2015), Ethiopia (Wilkes et al. 2020) and Kenya (SDL 2019). Adjustments were made to increase comparability: the IPCC values for the energy content of methane (55.65) and energy content of feed (18.45) were used in all calculations. Based on CSIRO (2007), DMD was converted to DE% using:

DE% = ((0.172*DMD-0.707)/0.81)/18.45*100.

Emission factors were estimated using both models for a total of 26 sub-categories of dairy cattle and 59 subcategories of beef ('other') cattle (Table 1). The reconstructed emission factors were compared with the reported EF values in each publication, and on average varied by <0.5%.

Comparisons were made between GEI, Ym (or Y) and the EF estimated using each model. In the absence of direct measurements from Africa, the comparison used Bland-Altman plots to explore the mean difference and variance in differences between estimates made using each model.

DAIRY CATTLE EMISSION FACTORS

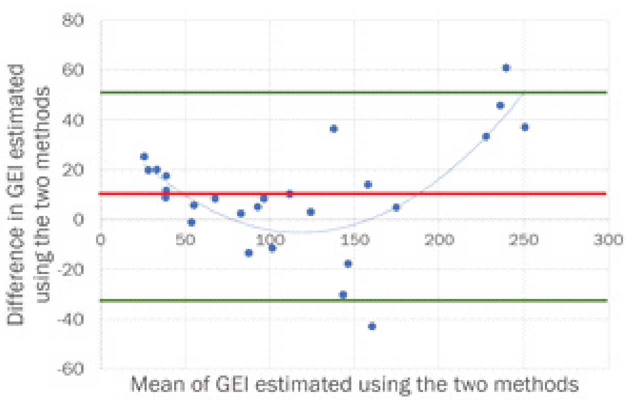
There was a high correlation between GEI estimates made using the two models (r^2=0.95). However, the South African model estimated higher GEI on average than the IPCC model. The mean difference in GEI was 10.2 MJ head^{-1} day^{-1} (s.d. = 22.7), which was significant ($P<0.05$) in a one-sample t-test. This difference is about 8.6% and 9.4% of GEI estimated using the S. African and IPCC models, respectively.

The curvilinear relationship in Figure 1 indicates that the South African model tended to estimate a higher GEI at low and high ranges of GEI, so the difference between methods is not consistent across the range of GEI. At low milk yields, net energy for maintenance is the main driver of energy intake in the IPCC model, and is the main parameter used to estimate DMI in the South African model.

Y in the S. African model and Ym in the IPCC model both represent % of GEI converted to methane. The Kenyan and Ethiopian inventories both adopted the IPCC (2006) default value of 6.5%. In the South African model, Y is calculated using the equation from Kurihara et al. (1999). Values of Y ranged between 7.17% and 8.48%, showing more variability than the IPCC default value.

Combining the differences in GEI and Y (or Ym), the mean difference in EFs estimated using the two models is 11.0 kg CH_4 head^{-1} day^{-1} (s.d. 11.8), with the South African model estimating higher EFs on average. This is due in part to the higher average estimate of GEI and also to the higher values of Y used. Similar to the pattern in Figure 1, the South African method tended to estimate a higher EF at low and high ranges of EF, so the difference between methods is not consistent across the range of EFs.

Figure 1: Bland-Altman Plot for dairy cattle GEI



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OTHER CATTLE EMISSION FACTORS

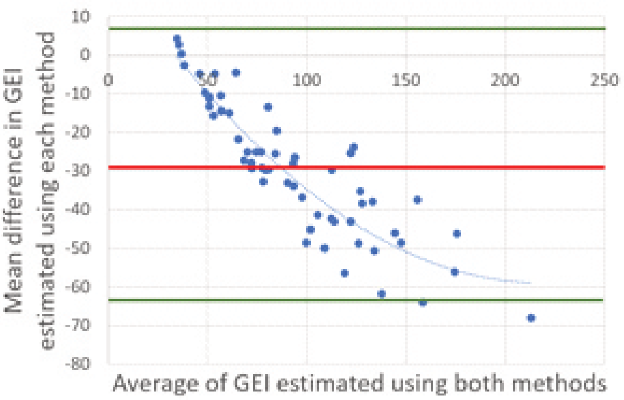
For other (beef or dual purpose) cattle, there was again a high correlation between GEI estimated using the IPCC and South African models, but the IPCC method consistently estimates a higher value of GEI, and the difference in GEI estimates was greater at higher levels of GEI.

The Bland-Altman Plot (Figure 2) shows that the mean difference in GEI was 29.4 MJ head-1 day-1 (s.d. = 17.3), which was significant ($P<0.05$) in a one-sample t-test. This difference is about 27% and 37% of average GEI estimated using the S. African and IPCC models, respectively. In the South African model, the EF is estimated directly from DMI, with no equivalent parameter for Y or Ym. In the data points from Kenya and Ethiopia, the IPCC default value of 6.5% was used. Benin used a value of 7.0%, which is consistent with IPCC (2019).

As a result, the average difference between EFs estimated using the two methods is 3.9 kg CH4 head-1 day-1 (s.d. 6.12), which is about 8-9% of the average EF estimated using either method. The IPCC method tends to estimate a higher EF than the South African method, and the bias increases as the EF increases.

If the updated Ym value of 7.0% for cattle on >75% forage from IPCC (2019) is applied to all beef cattle in Benin, Ethiopia and Kenya, the mean difference between EFs estimated using each model increases to 6.44 kg CH4 head-1 day-1 (s.d. 4.81), which is about 13-15% of the mean EF. However, the bias of higher mean EFs when using the IPCC model remains unchanged.

Figure 2: Bland-Altman Plot for other cattle GEI



OTHER CONSIDERATIONS

Without sufficient direct measurements to compare with, the preceding analysis was able only to demonstrate relative bias of the two models assessed, but cannot say which is more accurate. Considering that the IPCC default estimate of uncertainty for Tier 2 enteric fermentation is ±20%, differences in estimated EF of 8-10% for other cattle or 19-24% for dairy cattle are not trivial. These differences in estimated EF due to model choice can be considered when calculating inventory uncertainty.

In addition to accuracy, there are also other considerations. First, IPCC guidelines stress that uncertainty analysis is an essential part of inventory compilation. In both Kenya and Ethiopia, uncertainty analysis conducted using Monte Carlo simulation has proven to be extremely useful for targeting inventory improvement efforts. This was possible when using the IPCC model because uncertainty estimates for country-specific parameters as well as default coefficients are available. However, the South African model uses some intermediate parameters (e.g., metabolic rate when producing milk) for which there is little documentation of uncertainty. This makes it difficult to apply IPCC recommended uncertainty analysis methods, unless simplifying assumptions are used and margins of error are only applied to the activity data but not the fixed coefficients in the model.

Second, the two models differ in their data requirements and therefore in the ease of implementation. Table 2 indicates the activity data required by each model. The South African model for other cattle, in particular, has lower data requirements. Fewer parameters should mean that the South African model is more feasible in data-sparse countries. On the other hand, more parameters mean that the IPCC model is able to reflect the effects of a broader range of mitigation measures on GHG emissions. The South African model for beef cattle does not include feed quality values, and may be less useful for reflecting the effects of mitigation measures involving change in feed.

Finally, the Kurihara et al. (1999) model used to estimate the EF in the South African other cattle model was based on the Australian inventory. Australia subsequently adopted a revised equation based on Charmley et al. (2015): EF = 20.7 * DMI. It would be recommended to use this equation for other cattle.

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Table 2: Parameters required by each model

	Dairy cattle		Other cattle	
Parameter	**S. African model**	**IPCC model**	**S. African model**	**IPCC model**
Live weight	Yes	Yes	Yes	Yes
Mature weight	No	Yes	No	Yes
Weight gain per day	Yes	Yes	Yes	Yes
% cows giving birth	Yes	Yes	Yes	Yes
Milk yield	Yes	Yes	No	Yes
Fat content of milk	No	Yes	No	Yes
Hours worked	No	Yes	No	Yes
Feeding situation	No	Yes	No	Yes
Feed digestibility	Yes (DMD)	Yes (DE%)	No	Yes (DE%)
CH_4 conversion factor	(Calculated)	IPCC default	No	IPCC default

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This information note has been prepared as part of the 'Regional support to national livestock GHG inventories in Southern Africa' project, which has received financial support from the New Zealand Ministry for Primary Industries in support of the aims of the Global Research Alliance on Agricultural Greenhouse Gases. The Regional Support project is implemented by the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC), the Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN) and University of Pretoria. The views expressed in this document cannot be taken to reflect the official opinions of the organisations mentioned.