Chapter

Analysis of Inputs Parameters Used to Estimate Enteric Methane Emission Factors Applying a Tier 2 Model: Case Study of Native Cattle in Senegal

Séga Ndao

Abstract

In the context of the Paris Agreement, and considering the importance of methane emissions from cattle in West Africa, application of a Tier 2 method to estimate enteric methane emission factors is clearly pertinent. The current study has two purposes. Firstly, it aims to detect how much each input parameter contributes to the overall uncertainty of enteric methane emission factors for cattle. Secondly, it aims to identify which input parameters require additional research efforts for strengthening the evidence base, thus reducing the uncertainty of methane enteric emission factors. Uncertainty and sensitivity analysis methodologies were applied to input parameters in the calculation of enteric methane emission factors for lactating cows and adult male Senegalese native cattle using the IPCC Tier 2 model. The results show that the IPCC default input parameters, such as the coefficient for calculating net energy for maintenance ($C_{f_i}$), digestible energy (DE) and the methane conversion rate ($Y_m$) are the first, second and third most important input parameters, respectively, in terms of their contribution to uncertainty of the enteric methane emission factor. Sensitivity analysis demonstrated that future research in Senegal should prioritize the development of $Y_m$, $C_{f_i}$ and DE in order to estimate enteric methane emission factors more accurately and to reduce the uncertainty of the national agricultural greenhouse gas inventory.

Keywords: uncertainty analysis, sensitivity analysis, Tier 2 model, native cattle, Senegal

1. Introduction

The important role of the livestock sector in food security is well understood [1]. At the same time, the sector plays a significant role in greenhouse gas emissions to the atmosphere [2, 3]. Among total agriculture sector emissions (5.4 Gt CO2e), 60% is due to livestock emission sources, mostly (63%) enteric fermentation [4].

Within the United Nations Framework Convention on Climate Change (UNFCCC), developing countries are presently required to submit national GHG inventory reports through National Communications. These reports are to
be prepared following the Intergovernmental Panel on Climate Change (IPCC) Guidelines for GHG inventories [5]. The 2006 IPCC Guidelines set out three levels (or tiers) of increasing complexity (called Tiers 1–3) for use by a country. The purpose of the tiers is to provide unbiased and accurate estimates of national GHG emissions, and to enable inventory compilers to focus the use of resources on improving accuracy for key emission categories in the inventory. The Tier 1 method provides default values for GHG emissions per head of livestock and can reflect only variation in livestock numbers. The IPCC 2006 Tier 2 method for estimating enteric fermentation emissions from ruminants is based on net energy estimated using the National Research Council model [6]. This approach requires details on the characteristics of livestock sub-categories and their performance, for example, in terms of production (e.g., milk yield, daily weight gain) and reproduction (e.g., percentage of lactating cows).

At present, due to the scarcity of appropriate information on agricultural production in Sub-Saharan Africa (SSA), most countries in this region use the Tier 1 approach to quantify agricultural GHG emissions [7]. However, adopting the IPCC Tier 2 methodology can increase the accuracy of emission estimates [8]. In the SSA region [9, 10], provide enteric methane emission factors (EF) for cattle in South Africa and Benin, respectively, using the Tier 2 approach. A Tier 2 inventory for dairy cattle has also been produced by Kenya [11]. Since its second national communication in 2010, Senegal’s national GHG inventory, prepared by the Ministry of Environment, has used EFs calculated using a Tier 2 approach.

However, caution is required when applying the IPCC Tier 2 method to livestock systems in Africa. A recent study reported that the Tier 2 model had low predictive ability when the quality of diet changes [12]. In addition, estimation of enteric methane through the IPCC Tier 2 model assumes that animal is reared in ad libitum conditions throughout the year. In extensive livestock systems such as in West Africa, feedstuffs from grazing resources are typically available in the wet season but is very scarce during the dry season [13–15].

In recent years, further methods have been developed which allow highly accurate determination of emissions [16–18]. However, for developing countries, these measurement techniques may be very expensive and require significant knowledge to implement [19, 20]. Despite its possible shortcomings, therefore, the 2006 IPCC Tier 2 method is a practical method to estimate enteric methane emissions from cattle with greater accuracy than the default Tier 1 method [5].

Implementing a detailed uncertainty and sensitivity analysis of the input parameters in the IPCC Tier 2 model can provide guidance for targeting future research efforts to improve enteric fermentation estimates, with which to inform national GHG inventories, Nationally Appropriate Mitigation Actions (NAMAs) and Nationally Determined Contributions (NDCs).

In this study, the first objective is to use uncertainty analysis (UA) to identify which input parameters contribute significantly to the overall uncertainty of enteric methane emission factors estimated using the IPCC Tier 2 model. The second purpose is to apply sensitivity analysis (SA) in order to identify which parameters, need additional research, thereby increasing the accuracy of enteric methane emission factors.

2. Materials and methods

2.1 Location and livestock grazing systems

Senegal is the most westerly country in Africa with a tropical climate. It covers a surface area of 196,712 square kilometers and has an estimated population of 15.7
million [21]. Approximately 77% of the working population are employed in the agricultural sector [22]. According to the latest population estimates for the year 2018, the rural population represents about 53% of the total population [21]. The estimated ruminant livestock numbers provided by the Senegalese Ministry of Livestock and Animal Production (MEPA) are 3.6 million cattle, 6.7 million sheep and 5.7 million goats [23].

Extensive livestock farming systems in Senegal are based on two native cattle breeds which are found in different agroecological zones. The zebu Gobra (Bos indicus) and the taurine Ndama (Bos taurus) are mostly raised in the Northern and the Southern parts of Senegal, respectively [24]. The less common Gobra x Ndama crossbreed, termed Djakoré cattle, is located in the Senegalese groundnut basin. To improve national dairy production in Senegal, local cattle breeds are crossed with exotic dairy breeds e.g., Montbelliard, Holstein, through public funded artificial insemination campaigns [25]. To our knowledge, the proportion of the cattle breeds in Senegal has not been officially documented. However, inspection of regional livestock data from MEPA and the distribution area of cattle, our approximations suggest that the zebu Gobra and the taurine Ndama represent 80–90% of the Senegalese cattle population. In this case study, the zebu Gobra and the taurine Ndama cattle, which are the two dominant domestic cattle breeds, are considered. Particularly, lactating cows and adult males are the studied cattle sub-categories.

2.2 Description of the used model

Our evaluation was implemented using the Tier 2 model recommended by IPCC [5]. This model (Eq. (1)) allows to approximate enteric methane emission factors (MEF, kg CH4/head/year) which is the output variable. To calculate gross energy intake (GE, MJ/d), net energy (NE, MJ/d) needed for different metabolic functions (i.e., maintenance, activity, growth, lactation, work and pregnancy) was predicted for each cattle subcategory using various formulas presented in the IPCC Guidelines. The output variable is calculated based on input parameters, such as average live body weight (LW, kg), average daily weight gain (ADG, kg/day), milk production (Milk, kg/day), feeding situation, and digestible energy (DE, %). Finally, these parameters together with the methane (CH4) conversion factor (Ym, %) enable calculation of net energy (NE, MJ/day), average daily feed intake (in terms of gross energy content, MJ/d) and the MEF (i.e., output) for each animal sub-category.

\[
EF = \left[ \frac{(GE \times (Y_m/100) \times 365)}{55.65} \right] \tag{1}
\]

where:

- \( EF \) = emission factor, kg CH4 head/yr,
- \( GE \) = gross energy intake, MJ head/yr,
- \( Y_m \) = methane conversion factor, per cent of gross energy in feed converted to methane.

The factor 55.65, (MJ/kg CH4) is the energy content of methane.

2.3 Sources of input data

The data for input parameters used derived mainly from two Livestock Research Centres (LRC) of the Senegalese Agricultural Research Institute (Institut Sénégalais de Recherches Agricoles, ISRA, see www.isra.sn): the Centre de Recherches...
Zootechniques de Dahra (CRZ-D) and the Centre de Recherches Zootechniques de Kolda (CRZ-K). These LRCs are located in the Ferlo and the Casamance areas, respectively. The general focus of these LRCs is to disseminate bulls to Senegalese family farms, so as to maintain and improve the productivity (milk and meat) of indigenous cattle. CRZ-D and CRZ-K frequently collect data on reproductive (e.g., rank of calving, calving interval) and productive (e.g., LW, ADG, Milk) performance through surveys and direct measurements implemented as part of research programs conducted independently or in partnership with international research organizations (e.g., CIRAD, FAO).

For this study, research reports, theses, publications and data sourced from ISRA databases (http://intranet.isra.sn/aurifere/opac_css/) were examined for relevant information. Documents (e.g., annual reports) from the Senegalese Livestock Ministry (MEPA, http://www.elevage.gouv.sn/) and the National Agency for Statistics and Demography (ANSD, http://www.ansd.sn) were also consulted. When country-specific data was not available, values from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories was used. Table 1 presents the data sources used to estimate emission factors for Senegalese cattle breeds.

### Table 1

| Parameters                                      | Symbol | Unit       | References                |
|------------------------------------------------|--------|------------|---------------------------|
| Coefficient for calculating Net energy for maintenance | $C_f$  | MJ/d/kg    | [5]                       |
| Activity coefficient corresponding to animals’ feed situation | $C_a$  | MJ/d/kg    | [5]                       |
| Average live body weight                        | LW     | Kg         | CRZ-D database            |
| Mature live body weight                         | MW     | Kg         | From expert opinion       |
| Average daily weight gain                       | ADG    | kg/d       | [26–28] CRZ-K database    |
| Coefficient                                     | $C$    | dim.       | [5]                       |
| Average daily milk yield                        | Milk   | kg/d       | [24] CRZ-K Research reports |
| Fat content of milk                             | Fat    | %          | [29] CRZ-K Research reports |
| Number of hours of work                         | Hour   | H          | CRZ-D research reports    |
| Pregnancy coefficient                           | $C_p$  | dim.       | [5]                       |
| Methane conversion rates                        | $Y_m$  | %          | [5]                       |
| Feed Digestibility                              | DE     | %          | [5]                       |

*d: day; dim.: dimensionless; CRZ-D: Centre de Recherches Zootechniques de Dahra; CRZ-K: Centre de Recherches Zootechniques de Kolda.*

2.4 Uncertainty and sensitivity analysis procedures

Authors from many scientific fields have described the application of uncertainty analysis (UA) and sensitivity analysis (SA) procedures to various modeling techniques.
situations [30–32] and for a number of purposes [33]. For example, to achieve comprehensive uncertainty analysis, the 2006 IPCC Guidelines [5] recommend to use the Monte Carlo (MC) simulation method. The MC methodology is useful for dealing with great uncertainties, complex models and existing correlations between parameters [34, 35]. However, expanding the MC domain increases the requirements of the user, in terms of acquiring additional data and designing the analysis, and thus requires strong collaboration between experts [36]. For this present study, analysis of variance (ANOVA) and the standardized regression coefficient (SRC) were implemented for UA and SA, respectively.

Analysis was applied to emission factors for lactating cows (LC) and adult males (MA). The latest national communication indicates that these two animal classes are the largest emission sources among all cattle categories in Senegal [37]. For each of these animal categories, only the relevant parameters were estimated. For example, parameters such as milk yield (Milk, kg/day), fat content of milk (Fat, %) and the coefficient for pregnancy (Cp) were not estimated for MA, while number of hours of work (Hour, h/day) was not estimated for LC. Hence, 11 and 9 input parameters were considered for LC and MA, respectively. The number of simulations were 200,000 and 20,000 for LC and MA, respectively. These numbers were assumed to be satisfactory to stabilize the output. Indeed, a 3-level complete factorial design was defined [38] and considering the K dichotomous input parameters, the design requires $3^K$ simulations, i.e., 311 and 39 combinations of values for LC and MA, respectively [39].

2.4.1 Uncertainty analysis

Uncertainty analysis (UA) was applied to the enteric methane emission factors (MEF) of Senegalese native cattle derived using the IPCC Tier 2 method.

The input parameters characterized were from two main sources, i.e., parameters with values proposed by the 2006 IPCC Guidelines (PM) and parameters specific to extensive livestock farming systems in Senegal (PS).

The uncertainties of PM expressed in this study were those taken from the literature [5, 40]. The uncertainties of PS were not defined in the Senegalese NIR. Therefore, expert judgment was used to characterize the uncertainty of each PS. To do this, we proceeded as follows. The average value of each PS was estimated using livestock data reported from research conducted in Senegal. Then, these values were shared with national experts for assessment. These national specialists, who had worked previously on countrywide livestock research programs, suggested standard deviations around each mean values of PS, and these were used to represent relative uncertainties of each PS.

Consequently, an uncertainty of ±15% around the value of average live weight (LW, kg) and average daily gain (ADG, kg/day) were assumed. The fitted values of mature weight (MW, kg) had a relative uncertainty of ±25%. Milk production per lactating cow (Milk, kg/day) reported from the extensive livestock farming systems varies widely within and between Senegalese traditional farms, so an uncertainty range of ±20% was assumed, while the value of fat content of milk (Fat, %) was set to randomly fluctuate by ±2%. Regarding feed digestibility (DE, %), an uncertainty of ±15% is most commonly reported in the literature [40–42]. For this study, a value of ±20% was recommended by Senegalese experts, considering the extensive livestock farming systems, which are largely based on the use of rangeland forage resources. The probability density functions (PDFs) of all used input parameters is believed to be symmetrical.

The overall uncertainty in the estimated output is assumed to be normally distributed, with a 95% confidence interval of plus or minus the uncertainty of the
assigned value for each input parameter. The Tables 2 and 3 list the used values of the input parameters, for each breed and animal category.

To estimate the specific contribution of each parameter to overall uncertainty (i.e., uncertainty associated with calculation of enteric methane emission factors), the analysis of variance (ANOVA) procedure was applied. To do this, the uncertainty ranges related to the input parameters were used to define the maximum and minimum values of each input parameter. The distributions were defined as uniform (i.e., normal distributions). Then, using the "runif" instruction, input parameter values were randomly generated using R software [43]. To mimic the contributions of the generated values of each input parameter to output uncertainty, the equations proposed by the IPCC [5] were used. To rank the input parameters according to their effect on the output, the sums of the squares (Sum Sq) computed by the ANOVA procedure for each input parameter were divided by the total sums of squares. Therefore, the results were expressed as a proportion and ordered in terms of percentage contribution to output uncertainty, using the instruction order in the R software. The total uncertainty of enteric methane emission factors was calculated using Rule A [5], which is approximation approach based on first-order Taylor series expansion, often referred to as error propagations [44].

2.4.2 Sensitivity analysis

Some of the SA approach used in this study has been presented previously as a case study (see https://www.agmrv.org) for the Livestock Research Group of the Global Research Alliance for Agricultural Greenhouse Gases (https://globalre-searchalliance.org).

A sensitivity package developed by [45] and implemented in R software was used to conduct a global sensitivity analysis procedure [46]. First, to generate values between a minimum and the maximum, we set a range of variation of ±20% around the allocated value of each input parameter, assuming a uniform distribution (with a 95% confidence interval). Second, these values were input into the 2006 IPCC Tier 2 model to generate a range of values for the output. Finally, the standardized

| Symbol^1 | Unit | Used value^2 | Uncertainty (±%) | Sources of used uncertainties |
|----------|------|--------------|------------------|-----------------------------|
| ADG      | kg/day | 0.135 Gobra, 0.110 Ndama | 15               | Expert opinion |
| C        | dimensionless | 0.8 Gobra, 0.8 Ndama | 30               | [40]          |
| C_a      | MJ/day/kg | 0.36 Gobra, 0.36 Ndama | 30               | [40]          |
| C_f      | MJ/day/kg | 0.386 Gobra, 0.386 Ndama | 30               | [40]          |
| C_p      | dimensionless | 0.10 Gobra, 0.10 Ndama | 10               | [40]          |
| DE       | %      | 50 Gobra, 50 Ndama | 20               | Expert opinion |
| Fat      | %      | 4.7 Gobra, 4.24 Ndama | 2                | Expert opinion |
| LW       | kg     | 250 Gobra, 200 Ndama | 15               | Expert opinion |
| Milk     | kg/day | 0.922 Gobra, 0.870 Ndama | 20               | Expert opinion |
| MW       | kg     | 200 Gobra, 180 Ndama | 25               | Expert opinion |
| Y_m     | %      | 6.5 Gobra, 6.5 Ndama | 15               | [5]            |

1For the definition of symbols, see Table 1.
2For the sources of used values, see Table 1.

Table 2. Assigned values of input parameters used in the Tier 2 model to assess enteric methane emission factors for Gobra and Ndama lactating cows.
regression coefficient (SRC) was used to obtain sensitivity indices for each input parameter [47]. The SRC reflects the change in the standard deviation of the MEF when all other input parameters are fixed and unchanged [48, 49].

3. Results

3.1 Contribution of input parameters to uncertainty

The estimated values of the effect of each input parameter on overall uncertainty are presented in Tables 4 and 5 for lactating cows and adult males of the Gobra and Ndama cattle breeds, respectively.

The results show the effect of broad differences in the values for input parameters used in terms of their influence (expressed as a percentage, %) on overall uncertainty. The coefficient for maintenance (Cf_i) contributes more than 55% of the overall uncertainty. Digestibility (DE) and the methane conversion factor (Y_m) were the second and third most significant input parameters, respectively. The contributions of the other parameters were less than 10%.

In general, these results were similar for each animal sub-category of each breed, although there was some difference in terms of the contribution of these parameters to overall uncertainty. For example, with respect to lactating cows, the effect of Cf_i on the total uncertainty of the enteric methane EF calculation was greater for Gobra (58.2%) compared to Ndama (54.4%). By comparison, the contribution of Cf_i for adult males was 57.0% and 56.3% for Ndama and Gobra, respectively.

3.2 Sensitivity of used input parameters

Figures 1 and 2 show the standardized regression coefficients (SRC) of each input parameter used to evaluate the enteric methane emission factors for lactating cows and adult males of Senegalese native cattle, respectively.

According to the linear regression method implemented, the methane conversion rate (Y_m) and the coefficient for calculating net energy for maintenance (Cf_i) are the parameters with the largest SRC. The results show also the importance of the digestibility of feed (DE%) and liveweight (LW). The rank order in terms...
### Table 4.
Contribution to the overall uncertainty of input parameters used to calculate enteric methane emission factors for lactating cows of Senegalese native cattle breeds.

| Species | Parameters | Sum sq | Mean sq | F value | Pr (>F) | Contribution (%) |
|---------|------------|--------|---------|---------|---------|------------------|
| **Gobra** | Cf<sub>i</sub> | 6302301 | 6302301 | 7319021 | 0.000 | 58.2 |
|         | DE        | 2064336 | 2064336 | 2397366 | 0.000 | 19.1 |
|         | Y<sub>m</sub> | 1823864 | 1823864 | 2118099 | 0.000 | 16.8 |
|         | C<sub>a</sub> | 350673  | 350673  | 407245  | 0.000 | 3.2 |
|         | LW        | 96244   | 96244   | 111770  | 0.000 | 0.9 |
|         | Milk      | 20210   | 20210   | 23470   | 0.000 | 0.2 |
|         | C<sub>p</sub> | 3330   | 3330   | 3867    | 0.000 | 0.0 |
|         | ADG       | 109     | 109     | 127     | 0.000 | 0.0 |
|         | Fat       | 83      | 83      | 96      | 0.000 | 0.0 |
|         | C         | 66      | 66      | 77      | 0.000 | 0.0 |
|         | MW        | 16      | 16      | 18      | 0.000 | 0.0 |
|         | Residuals | 172207  | 1       | NA      | NA    | 1.6 |
| **Ndama** | Cf<sub>i</sub> | 4509591 | 4509591 | 6005876 | 0.000 | 54.4 |
|         | DE        | 1438224 | 1438224 | 1915428 | 0.000 | 17.3 |
|         | Y<sub>m</sub> | 1293936 | 1293936 | 1723265 | 0.000 | 15.6 |
|         | LW        | 625802  | 625802  | 833444  | 0.000 | 7.5 |
|         | C<sub>a</sub> | 253737  | 253737  | 337927  | 0.000 | 3.1 |
|         | Milk      | 15579   | 15579   | 20748   | 0.000 | 0.2 |
|         | C<sub>p</sub> | 2938  | 2938  | 3913    | 0.000 | 0.0 |
|         | Fat       | 119     | 119     | 158     | 0.000 | 0.0 |
|         | MW        | 72      | 72      | 95      | 0.000 | 0.0 |
|         | C         | 68      | 68      | 90      | 0.000 | 0.0 |
|         | ADG       | 0       | 0       | 0       | 0.659 | 0.0 |
|         | Residuals | 150164  | 1       | NA      | NA    | 1.8 |

NA: not applicable.
of sensitivity was identical for both cattle breeds and each animal sub-category. Moreover, our results reveal that among breeds, the SRC obtained for Ndama cattle was slightly larger. Differences were also observed between sub-categories. Compared to lactating cows, the SRC was higher for adult male Gobra cattle for parameters such as $Y_m$, $C_f$, and $LW$. For lactating cows, compared with adult males, $Y_m$ and $DE$ showed more sensitivity for Ndama cattle. However, irrespective of breed or sub-category, the differences observed between SRC of input parameters did not exceed 8%.

Table 5.
Contribution to the overall uncertainty of input parameters used to calculate enteric methane emission factors for adult male Senegalese native cattle breeds.

| Species | Parameters | Sum sq | Mean sq | F value | Pr (>F) | Contribution (%) |
|---------|------------|--------|---------|---------|---------|------------------|
| Ndama   | $C_f$      | 595693 | 595693  | 611755  | 0.000   | 57.0             |
|         | $DE$       | 161026 | 161026  | 165368  | 0.000   | 15.4             |
|         | $Y_m$      | 148597 | 148597  | 152604  | 0.000   | 14.2             |
|         | $LW$       | 82999  | 82999   | 85237   | 0.000   | 7.9              |
|         | $C_a$      | 37722  | 37722   | 38739   | 0.000   | 3.6              |
|         | Hour       | 276    | 276     | 284     | 0.000   | 0.0              |
|         | $MW$       | 14     | 14      | 15      | 0.000   | 0.0              |
|         | C          | 1      | 1       | 1       | 0.273   | 0.0              |
|         | $ADG$      | 0      | 0       | 0       | 0.746   | 0.0              |
|         | Residuals  | 19465  | 1       | NA      | NA      | 1.9              |

*NA: not applicable.*

Figure 1.
Sensitivity indices based on standardized regression coefficients of input parameters used to calculate enteric methane emission factors for lactating cows of Senegalese native cattle breeds.
4. Discussion

4.1 Moving to a Tier 2 enteric methane emission factor

To date, because of the scarcity of relevant data in developing countries in the SSA region, the Tier 1 approach is most commonly used to evaluate enteric methane emission from livestock [50, 51]. Assessments at the regional level suggest that Africa has a higher uncertainty for each livestock product compared with Europe [52]. Additionally, [8] reported that only about one third of countries located in developing regions have conducted evaluation of uncertainty in their national GHG inventory. Considering the absence of reliable information on livestock in the SSA region, the IPCC Guidelines suggest that the uncertainty of enteric fermentation emission factors ranges from ±30% to ±50% for Tier 1 and ±20% for Tier 2 approaches, respectively [5]. Hence, the use of a Tier 2 approach may enable a decrease in the uncertainty of predicted enteric methane emission factors used in national GHG inventories [53–55]. In Senegal, the third GHG emission inventory was submitted to the UNFCCC in 2015 (see https://unfccc.int/documents/89618). In that inventory, enteric methane emission of cattle was assessed using the Tier 2 methodology. Within the overall emissions from the agricultural sector, enteric methane was identified as a key source of emissions (accounting for 72% of total agricultural emissions). Cattle were responsible for 65% of total agricultural emissions. However, uncertainty analysis has not previously been performed on that national GHG inventory.

4.2 Importance of input parameters

Considering the results of both uncertainty and sensitivity analysis computed in this study, our calculations indicate that the coefficient of maintenance (Cf),
the digestibility of feed (DE) and the methane conversion factor \( (Y_m) \) are the input parameters which require further research, because of their influence on the accuracy of enteric methane emission factors calculated using the 2006 IPCC Tier 2 approach.

The importance of \( C_f \) has been pointed out in previous research conducted in other regions \([41, 42, 53]\). The value of \( C_f \) implemented in our assessment was sourced from the IPCC Guidelines. To our knowledge, studies focusing on this parameter are very few, particularly in developing countries, despite the dependence of this parameter on variation in temperature \([5]\).

The composition of fodder consumed by ruminants is well documented in Senegal, and the profile of organic matter digestibility \( \text{OMd} \) is available \([13–15, 54]\). However, there is a need to determine at the national scale, an average value for \( \text{OMd} \) which takes into consideration seasonality. To date, the default value for feed digestibility \( \text{DE} \) \( \% \) from the IPCC Guidelines \( \text{i.e., } 50 \pm 5\% \) has always been applied in the Senegalese national GHG inventory. In general, estimation of \( \text{DE} \) is very complex, considering the various factors which need to be taken into consideration \([56–58]\). To estimate \( \text{DE} \), robust formula needs to be developed based on numerous data which consider the diversity of diet \([59]\). For example, in West African livestock farming systems, the largest proportion of feed is from natural pastures \([60–62]\). Cattle herds in this region graze different types of feedstuffs \( \text{e.g., } \) trees, crop residues, woody species, grasses). Throughout the seasons, the composition of the diet and the nutrient content of feedstuff both fluctuate \([13, 63, 64]\). Given the diversity of feedstuff and seasonal fluctuations in the West African context, determining an annual average value of \( \text{DE} \) is challenging. A fixed value for \( \text{DE} \) is reasonable as it is supposed to represent the annual average. Additionally, apart from the proposed values of \( \text{DE} \) in the 2006 IPCC Guidelines, reports of the value of \( \text{DE} \) are very limited in the literature, even in some developed countries. Indeed, with the lack of country-specific data related to the feeding system, Belgium applies \( \text{DE} \) values from the Netherlands, assuming that feed systems are comparable \([65]\). Slovenia uses a predicted equation sourced from INRA and German feeding tables \([66]\). In the national inventory of the UK, the \( \text{DE} \) values applied for dairy cattle were from tables of nutritive value and chemical composition of feeds, while for beef cattle values were based on expert opinion \([67]\).

The methane conversion factor \( (Y_m, \%) \) is the third parameter which needs to be better estimated when using the Tier 2 approach. \( Y_m \) is defined as the percent of gross energy intake that is converted into methane \( (\text{kg CH4/kg GEI}) \). The appropriate value of \( Y_m \) is the subject of considerable research by scientists \([68]\). Using a meta-analysis approach, \([69]\) propose using \( 8.4 \pm 0.4\% \) \( \text{range 4.8\% to 13.7\%} \) for \( Y_m \), while \([70]\) suggest a value which varies from \( 5.0\% \) to \( 7.2\% \). Several countries apply values for \( Y_m \) other than the default values suggested by the 2006 IPCC Guidelines. For example, Croatia calculated \( Y_m \) using a model reported by \([56]\). Denmark used a value for \( Y_m \) for dairy cattle \( \text{ranging from 5.98\% to 6.13\%} \) reported by \([71]\).

Hence, in view of the diverse diet composition consumed by cattle over the course of the seasons in West Africa \([72–74]\), determination of an appropriate value for \( Y_m \) is clearly important for estimating the expected enteric methane emission factor using the IPCC 2006 Tier 2 approach.

In our case, we used expert judgment to characterize the uncertainties of input parameters. In addition, it is possible that the inputs parameters can be correlated. In Senegal, due to the scarcity of relevant reports related to the percentage of native cattle breeds in the total cattle herd, it is probable that uncertainty of activity data is actually higher than uncertainty of emission factors and should be a priority for GHG inventory improvement.
5. Conclusions

The purpose of conducting uncertainty and sensitivity analysis was to identify the most important factors driving emission factors in order to prioritize future data improvement and research efforts so as to improve livestock GHG emission estimates and reduce the uncertainty of inventory estimates for Senegal. Having applied analysis of variance and regression techniques for uncertainty analysis and sensitivity analysis, respectively, our results suggest that future research should focus on the estimates of the coefficient of maintenance, feed digestibility and the methane conversion factor.

Acknowledgements

We thank colleagues who contributed to improving this manuscript.

Conflict of interest

The author declares that no conflicts of interest have affected the conduct of the work proposed in this paper.

Author details

Séga Ndao
ISRA, Centre de Recherches Zootechniques de Kolda, Kolda, Senegal

*Address all correspondence to: ndaosega@gmail.com
References

[1] Godber, O. F., & Wall, R. (2014). Livestock and food security: vulnerability to population growth and climate change. Global change biology, 20(10), 3092-3102.

[2] Steinfeld, H., Gerber, P., Wassenaar, T. D., Castel, V., Rosales, M., Rosales, M., & de Haan, C. (2006). Livestock's long shadow: environmental issues and options. Food & Agriculture Org.

[3] Gerber, P. J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., ... & Tempio, G. (2013). Tackling climate change through livestock: a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO).

[4] Tubiello, F. N., Cóndor-Golec, R. D., Salvatore, M., Piersante, A., Federici, S., Ferrara, A., ... & Jacobs, H. (2015). Estimating greenhouse gas emissions in agriculture: a manual to address data requirements for developing countries. Estimating greenhouse gas emissions in agriculture: a manual to address data requirements for developing countries.

[5] Eggleston, S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K. (Eds.). (2006). 2006 IPCC guidelines for national greenhouse gas inventories (Vol. 5). Hayama, Japan: Institute for Global Environmental Strategies.

[6] National Research Council. (1989). Recommended dietary allowances. National Academies Press.

[7] Rosenstock, T. S., Rufino, M. C., Butterbach-Bahl, K., & Wollenberg, E. (2013). Toward a protocol for quantifying the greenhouse gas balance and identifying mitigation options in smallholder farming systems. Environmental Research Letters, 8(2), 021003.

[8] Wilkes, A., Reisinger, A., Wollenberg, E. and van Dijk, S. (2017). Measurement, reporting and verification of livestock GHG emissions by developing countries in the UNFCCC: current practices and opportunities for improvement. CCAFS Report No. 17. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and Global Research Alliance for Agricultural Greenhouse Gases (GRA).

[9] Du Toit, C. J. L., Meissner, H. H., & Van Niekerk, W. A. (2013). Direct methane and nitrous oxide emissions of South African dairy and beef cattle. South African Journal of Animal Science, 43(3), 320-339.

[10] Kouazounde, J. B., Gbenou, J. D., Babatounde, S., Srivastava, N., Eggleston, S. H., Antwi, C., ... & McAllister, T. A. (2015). Development of methane emission factors for enteric fermentation in cattle from Benin using IPCC Tier 2 methodology. animal, 9(3), 526-533.

[11] State Department for Livestock (SDL). (2020). Inventory of GHG emissions from dairy cattle in Kenya 1994-2017. State Department for Livestock, Nairobi. http://www.kilimo.go.ke/wp-content/uploads/2020/07/Kenya-Dairy-Cattle-GHG-inventory-Report_06_07_2020.pdf

[12] Benaouda, M., Martin, C., Li, X., Kebreab, E., Hristov, A. N., Yu, Z., ... & Bannink, A. (2019). Evaluation of the performance of existing mathematical models predicting enteric methane emissions from ruminants: animal categories and dietary mitigation strategies. Animal Feed Science and Technology, 114207.

[13] Ickowicz, A., and Mbaye, M. (2001). Forêts soudaniennes et alimentation des bovins au Sénégal:
potentiel et limites. Bois et forêts des tropiques, (270), 47-61.

[14] Chirat, G., Groot, J. C., Messad, S., Bocquier, F., & Ickowicz, A. (2014). Instantaneous intake rate of free-grazing cattle as affected by herbage characteristics in heterogeneous tropical agro-pastoral landscapes. Applied Animal Behaviour Science, 157, 48-60.

[15] Assouma, M. H., Lecomte, P., Hiernaux, P., Ickowicz, A., Corniaux, C., Decruyenaere, V., ... & Vayssières, J. (2018). How to better account for livestock diversity and fodder seasonality in assessing the fodder intake of livestock grazing semi-arid sub-Saharan Africa rangelands. Livestock Science, 216, 16-23.

[16] Kebreab, E., Johnson, K. A., Archibeque, S. L., Pape, D., & Wirth, T. (2008). Model for estimating enteric methane emissions from United States dairy and feedlot cattle. Journal of animal science, 86(10), 2738-2748.

[17] Goopy, J. P., Woodgate, R., Donaldson, A., Robinson, D. L., & Hegarty, R. S. (2011). Validation of a short-term methane measurement using portable static chambers to estimate daily methane production in sheep. Animal Feed Science and Technology, 166, 219-226.

[18] Huhtanen, P., Ramin, M., & Hristov, A. N. (2019). Enteric methane emission can be reliably measured by the GreenFeed monitoring unit. Livestock science, 222, 31-40.

[19] Powers, W., Auvermann, B., Cole, A., Gooch, C., Grant, R., Hatfield, J., . . . Powell, J. M. (2014). Chapter 5: Quantifying Greenhouse Gas Sources and Sinks in Animal Production Systems. In Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory. Office of the Chief Economist, U.S. Department of Agriculture. Washington. DC.: USDA

[20] Hammond, K. J., Crompton, L. A., Bannink, A., Dijkstra, J., Yáñez-Ruiz, D. R., O’Kiely, P., ... & Schwarm, A. (2016). Review of current in vivo measurement techniques for quantifying enteric methane emission from ruminants. Animal Feed Science and Technology, 219, 13-30.

[21] ANSD. (2018). Rapport projection de la population du Sénégal en 2018. Division du recensement et des statistiques démographiques. Direction des statistiques démographiques et sociales. Accessed August 10, 2019: http://www.ansd.sn/ressources/publications/Rapport_population_060219%20002%20RECsn%20.pdf.

[22] Roy-Macauley, H., Zougmoré, R., Nelson, G. C., & Jalloh, A. (2017). L’agriculture Ouest-Africaine et le changement climatique. Intl Food Policy Res Inst.

[23] MEPA. (2016). Rapport d'activités du Ministère de l'Élevage et des Productions Animales. Available at : http://www.elevage.gouv.sn/sites/default/files/Rapport_MEPA_2016.pdf

[24] ISRA. (2005). Bilan de la recherche agricole et agroalimentaire au Sénégal. Institut Sénégalais de Recherches Agricoles. Dakar. ISRA-ITA-CIRAD.

[25] Marshall, K., Gibson, J. P., Mwai, O., Mwacharo, J. M., Haile, A., Getachew, T., ... & Kemp, S. J. (2019). Livestock Genomics for Developing Countries–African Examples in Practice. Frontiers in genetics, 10.

[26] Sow, I., S. R., Denis, J., Trail, J., Thiongane, P., Mbaye, M., & Diallo. 1988. (1988). Productivité du zébu Gobra au Centre de Recherches Zootechniques de Dahra (Senegal). Institut Sénégalais de Recherches
Analysis of Inputs Parameters Used to Estimate Enteric Methane Emission Factors Applying...
DOI: http://dx.doi.org/10.5772/intechopen.99810

Agricoles, Recherches Sante et Productions Animales. Unival.

[27] Diop, M. (1990). Les Systèmes d’élevage Dans Le Ferlo : Etude synthétique de la Situation actuelle. Papier préparé pour le séminaire sur “Les systèmes de production de lait et de viande au Sahel. ISRA-EISMV.

[28] Mbaye, M., Diop, M. and Ndiaye, M. (1991). Etude de la puberté et des paramètres de production du zebu Gobra en milieu traditionnel. ISRA-EISMV.

[29] Kalandi, M., Sow, A., Guigma, W. V. H., Zabre, M. Z., Bathily, A., & Sawadogo, G. J. (2015). Evaluation de la qualité nutritionnelle du lait cru dans les élevages traditionnels de Kaolack au Sénégal. International Journal of Biological and Chemical Sciences, 9(2), 901-909.

[30] Saltelli, Andrea. (2002). Sensitivity analysis for importance assessment. Risk Analysis 22 (3): 579-590.

[31] Makowski, D., Naud, C., Jeuffroy, M. H., Barbottin, A., & Monod, H. (2006). Global sensitivity analysis for calculating the contribution of genetic parameters to the variance of crop model prediction. Reliability Engineering & System Safety, 91(10-11), 1142-1147.

[32] Iooss, B. (2011). Revue sur l’analyse de sensibilité globale de modèles numériques. Journal de la Société Française de Statistique, 152(1), 1-23.

[33] Hamby, D. M. (1994). A review of techniques for parameter sensitivity analysis of environmental models. Environmental monitoring and assessment, 32(2), 135-154.

[34] Gibbons, J. M., Ramsden, S. J., & Blake, A. (2006). Modelling uncertainty in greenhouse gas emissions from UK agriculture at the farm level.

[35] Ortiz-Gonzalo, D., Vaast, P., Oelofse, M., de Neergaard, A., Albrecht, A., & Rosenstock, T. S. (2017). Farm-scale greenhouse gas balances, hotspots and uncertainties in smallholder crop-livestock systems in Central Kenya. Agriculture, Ecosystems & Environment, 248, 58-70.

[36] Fauser, P., Sørensen, P. B., Nielsen, M., Winther, M., Plejdrup, M. S., Hoffmann, L., ... & Thomsen, M. (2011). Monte Carlo (Tier 2) uncertainty analysis of Danish greenhouse gas emission inventory. Greenhouse Gas Measurement and Management, 1(3-4), 145-160.

[37] Senegal NIR. (2015). Accessed June 6, 2019 at: https://unfccc.int/sites/default/files/resource/Senncc3.pdf.

[38] Makowski, D. (2013). Objectifs et principales étapes de l’analyse d’incertitude et de sensibilité. Analyse de sensibilité et exploration de modèles. Editions Quae, Versailles, 3-30.

[39] Dziak, J. J., Nahum-Shani, I., & Collins, L. M. (2012). Multilevel factorial experiments for developing behavioral interventions: Power, sample size, and resource considerations. Psychological methods, 17(2), 153.

[40] Monni, S., Perälä, P., & Regina, K. (2007). Uncertainty in agricultural CH4 and N2O emissions from Finland—possibilities to increase accuracy in emission estimates. Mitigation and adaptation strategies for global change, 12(4), 545-571.

[41] Karimi-Zindashty, Y., MacDonald, J. D., Desjardins, R. L., Worth, D. E., Hutchinson, J. J., & Vergé, X. P. C. (2012). Sources of uncertainty in the IPCC Tier 2 Canadian livestock model. The Journal of Agricultural Science, 150(5), 556-569.
Annual methane budgets of sheep grazing systems were regulated by grazing intensities in the temperate continental steppe: A two-year case study. Atmospheric environment, 174, 66-75.

Ndung’u, P. W., Bebe, B. O., Ondiek, J. O., Butterbach-Bahl, K., Merbold, L., & Goopy, J. P. (2019). Improved region-specific emission factors for enteric methane emissions from cattle in smallholder mixed crop: livestock systems of Nandi County, Kenya. Animal Production Science, 59(6), 1136-1146.

Zhu, B., Kros, J., Lesschen, J. P., Staritsky, I. G., & de Vries, W. (2016). Assessment of uncertainties in greenhouse gas emission profiles of livestock sectors in Africa, Latin America and Europe. Regional Environmental Change, 16(6), 1571-1582.

Patra, A. K. (2012). Estimation of methane and nitrous oxide emissions from Indian livestock. Journal of Environmental Monitoring, 14(10), 2673-2684.
review of enteric methane mitigation options. Journal of animal science, 91(11), 5045-5069.

[57] Descheemaeker, K., Oosting, S. J., Tui, S. H. K., Masikati, P., Falconnier, G. N., & Giller, K. E. (2016). Climate change adaptation and mitigation in smallholder crop–livestock systems in sub-Saharan Africa: a call for integrated impact assessments. Regional Environmental Change, 16(8), 2331-2343.

[58] Brandt, P., Herold, M., & Rufino, M. C. (2018). The contribution of sectoral climate change mitigation options to national targets: a quantitative assessment of dairy production in Kenya. Environmental Research Letters, 13(3), 034016.

[59] Eugène, M., Sauvant, D., Nozière, P., Viallard, D., Oueslati, K., Lherm, M., ... & Doreau, M. (2019). A new Tier 3 method to calculate methane emission inventory for ruminants. Journal of environmental management, 231, 982-988.

[60] Gautier, D., Bonnérat, A., & Njoua, A. (2005). The relationship between herders and trees in space and time in northern Cameroon. Geographical Journal, 171(4), 324-339.

[61] Ouédraogo-Koné, S., Kaboré-Zoungrana, C. Y., & Ledin, I. (2006). Behaviour of goats, sheep and cattle on natural pasture in the sub-humid zone of West Africa. Livestock Science, 105(1-3), 244-252.

[62] Tongwane, M. I., & Moeletsi, M. E. (2018). A review of greenhouse gas emissions from the agriculture sector in Africa. Agricultural Systems, 166, 124-134.

[63] Touré, S. F., Michalet-Doreau, B., Traoré, E., Friot, D., & Richard, D. (1998). Occurrence of digestive interactions in tree forage-based diets for sheep. Animal Feed Science and Technology, 74(1), 63-78.

[64] Amole T.A., Ayantunde A. A. (2016). Climate-smart livestock interventions in West Africa: A review. CCAFS Working Paper no. 178. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

[65] Belgium NIR (2018). Accessed August 20, 2019 at: https://unfccc.int/documents/65711

[66] Slovenia NIR. (2018). Accessed June 6, 2019 at: https://unfccc.int/documents/65714

[67] UK NIR. (2018). Accessed August 22, 2019 at: https://unfccc.int/documents/65762

[68] Van Lingen, H. J., Niu, M., Kebreab, E., Valadares Filho, S. C., Rooke, J. A., Duthie, C. A., ... & Eugène, M. (2019). Prediction of enteric methane production, yield and intensity of beef cattle using an intercontinental database. Agriculture, Ecosystems & Environment, 283, 106575.

[69] Kaewpila, C., & Sommart, K. (2016). Development of methane conversion factor models for Zebu beef cattle fed low-quality crop residues and by-products in tropical regions. Ecology and evolution, 6(20), 7422-7432.

[70] Kennedy, P. M., & Charmley, E. (2012). Methane yields from Brahman cattle fed tropical grasses and legumes. Animal Production Science, 52(4), 225-239.

[71] Hellwing, A. L. F., Weisbjerg, M. R., Brask, M., Alstrup, L., Johansen, M., Hymøller, L., ... & Lund, P. (2016). Prediction of the methane conversion factor (Ym) for dairy cows on the basis
of national farm data. Animal production science, 56(3), 535-540.

[72] Archimède, H., Eugène, M., Magdeleine, C. M., Boval, M., Martin, C., Morgavi, D. P., ... & Doreau, M. (2011). Comparison of methane production between C3 and C4 grasses and legumes. Animal Feed Science and Technology, 166, 59-64.

[73] Nicholson, S. E. (2013). The West African Sahel: A review of recent studies on the rainfall regime and its interannual variability. ISRN Meteorology, 2013.

[74] Taugourdeau, S., Daget, P., Chatelain, C., Mathieu, D., Juanes, X., Huguenin, J., & Ickowicz, A. (2019). FLOTROP, a massive contribution to plant diversity data for open ecosystems in northern tropical africa. Scientific data, 6(1), 118.