Development of methane emission factors for enteric fermentation in cattle from Benin using IPCC Tier 2 methodology

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The objective of this study was to develop emission factors (EF) for methane (CH₄) emissions from enteric fermentation in cattle native to Benin. Information on livestock characteristics and diet practices specific to the Benin cattle population were gathered from a variety of sources and used to estimate EF according to Tier 2 methodology of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Most cattle from Benin are Bos taurus represented by Borgou, Somba and Lagune breeds. They are mainly multi-purpose, being used for production of meat, milk, hides and draft power and grazed in open pastures and crop lands comprising tropical forages and crops. Estimated enteric CH₄ EFs varied among cattle breeds and subcategory owing to differences in proportions of gross energy intake expended to meet maintenance, production and activity. EFs ranged from 15.0 to 43.6, 16.9 to 46.3 and 24.7 to 64.9 kg CH₄/head per year for subcategories of Lagune, Somba and Borgou cattle, respectively. Average EFs for cattle breeds were 24.8, 29.5 and 40.2 kg CH₄/head per year for Lagune, Somba and Borgou cattle, respectively. The national EF for cattle from Benin was 39.5 kg CH₄/head per year. This estimated EF was 27.4% higher than the default EF suggested by IPCC for African cattle with the exception of dairy cattle. The outcome of the study underscores the importance of obtaining country-specific EF to estimate global enteric CH₄ emissions.

Keywords: methane, enteric fermentation, emission factor, cattle, Benin, Africa

Implications
Methane (CH₄) is second to carbon dioxide in terms of its contribution to climate change (Lassey, 2007). More than 70% of CH₄ is generated by anthropogenic activities including animal husbandry (27%), enteric fermentation in livestock, manure management, paddy rice cultivation (26%), petroleum sources (26%), waste management (13%) and 9% from biomass burning (Kvenvolden and Rogers, 2005; Sejian et al., 2012). Enteric fermentation is the largest source of CH₄ from ruminant livestock with cattle being the major contributor. Cattle emit CH₄ as a result of intestinal fermentation and identification of those geographical regions where this source is significant is required for targeted mitigation. There is a paucity of information on enteric CH₄ emissions in regions of Africa. Use of Tier 2 methodology of the Intergovernmental Panel on Climate Change (IPCC) (2006) improves estimates and reduces uncertainties around enteric CH₄ emissions from cattle. The present paper compiled country-specific data to develop emission factors to more accurately estimate enteric CH₄ emissions from cattle in Benin, Africa.

Introduction
Scientific evidence established by the Intergovernmental Panel on Climate Change (IPCC) reveals that increasing greenhouse gas (GHG) concentrations in the atmosphere attributable to human activities are responsible for global climate change (IPCC, 2007). The contribution of GHGs namely, carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and halocarbons to global anthropogenic emissions in 2010 expressed as CO₂ equivalents (CO₂eq) were estimated at 76%, 16%, 6% and 2%, respectively (Olivier and Janssens-Maenhout, 2012). In 2000, the main GHG in Benin...
was N\textsubscript{2}O, accounting for 40\% of CO\textsubscript{2}eq emissions, followed by CH\textsubscript{4} (37\%) and CO\textsubscript{2} (23\%) (Ministry of Environment, Urban Settlement and Town Planning (MEHU), 2011). Agriculture was the main source of GHG in Benin, accounting for ~68\% of total CO\textsubscript{2}eq emissions in 2000 with enteric CH\textsubscript{4} mainly from cattle (84\%), accounting for 29\% of emissions from this sector (MEHU, 2011).

The effectiveness of any global measure to combat the threat of climate change will depend significantly on the accuracy of country-specific national GHG inventories. These inventories support the prediction of GHG emission trends and in assessing the potential value of mitigation options. However, a previous review of national GHG inventories from West African countries including Benin revealed high uncertainties largely caused by gaps in activity data and the use of IPCC default emission factors (EFs) that did not reflect West African conditions (United Nations Development Programme (UNDP), 2002). Indeed, national GHG inventories are performed in West Africa mainly using Tier 1 methodology as outlined in IPCC guidelines. The GHG inventory methods given in the IPCC guidelines estimate emissions based on the extent to which a human activity takes place (activity data) along with an EF which quantify emissions or removals per unit of activity using the following equation:

\[
\text{Emissions} = AD \times EF \tag{1}
\]

For estimating CH\textsubscript{4} from enteric fermentation, methodologies in IPCC guidelines vary from the simpler Tier 1 approach towards the increasingly more complex Tier 2 and Tier 3 methods (IPCC (2006)). Tier 1 methods involve using the default enteric CH\textsubscript{4} EFs, which provide fixed values for each species of animal in different regions of the World, irrespective of variations in animal physiological state or production level. Tier 2 methods substitute default EFs with those that are country specific, to more accurately reflect country-specific information on livestock populations and feed and feed intake characteristics. Tier 3 methods are also country specific and involve modeling and or detailed measurements that are expected to provide the most accurate estimate of emissions (IPCC (2006)), requirements that are difficult in nations where financial and specialized human resources are limited and novel types of equipment whose cost and maintenance may not be within the scope of many laboratories. At present, national inventories of enteric CH\textsubscript{4} emissions are estimated in Benin using IPCC Tier 1 methods. Among EFs contributing to uncertainty in the estimation of West African GHG emissions, enteric fermentation from domestic livestock was second only to forest and grassland conversion (UNDP, 2002). The lack of a country-specific enteric CH\textsubscript{4} EF that reflect Benin production practices impedes accurate estimation of agricultural emissions (MEHU, 2011). One of the main future improvements identified in Benin national GHG inventory system is the need of enteric CH\textsubscript{4} from cattle to be estimated using IPCC Tier 2 methodology.

This study aimed to develop enteric CH\textsubscript{4} EFs for cattle native to Benin using Tier 2 methodology following the 2006 IPCC Guidelines for National GHG Inventories.

### Material and methods

Enteric CH\textsubscript{4} EFs (annual CH\textsubscript{4} emissions per animal) for cattle that are used for multi-purpose within Benin were estimated using the Tier 2 method of IPCC (2006) which is based on National Research Council (NRC) (1996) energy model. The steps as outlined in Figure 1 were used to estimate EFs.

### Collection of input data

Data related to the characterization of cattle populations and the description of performance and diet by cattle subcategory were collected from sources of country-specific data as suggested by IPCC protocols through a literature search of national libraries (University of Abomey-Calavi of Benin, Livestock Department of Benin, Ministry in charge of Environment in Benin), publications in scientific journals and data compiled by the IPCC (2006), the Food and Agriculture Organization (FAO), the International Livestock Research Institute (ILRI) and the International Livestock Centre for Africa (ILCA). Thus, scientific and technical articles (17), dissertations (7), project reports (2), national inventory reports of agriculture sector from Benin (1), consultative groups on international agricultural research (ILRI, ILCA) or international organizations (FAO, IPCC) were consulted. Collected data included that generated by studies carried out on cattle bred in traditional production systems (see ‘Feeding situation’ section) and studies designed to improve cattle productivity.

Data related to some of the Benin cattle breeds were sparse (reproduction trait for all cattle, live BW for Borgou cattle) or not available (average weight gain per day for Borgou and Lagune cattle, live BW for Lagune cattle) as censuses on livestock population and characteristics are not carried out on a regular basis. Under these conditions, additional data were derived from expert opinion and compiled from Togo (West African country) as suggested by IPCC protocols (IPCC, 2006). Traditional cattle production systems (see ‘Feeding situation’ section) are the dominant production systems in Benin (Ministère de l’Agriculture et de l’Elevage (MAEP), 2003) and consequently this production system constituted the majority of the data in deriving EF estimates.

In the absence of such data, estimated average weight gain per day for Borgou and Lagune cattle, live BW data of Lagune cattle bred under similar production and climate conditions in Togo (tropical soudanian climate in the North and sub-equatorial climate in the South) and average weight gain of Borgou cattle of 6 to 12 months from improved systems in Benin were used.

### Characterization of cattle population and performance data of cattle subcategories.

Compiled data were summarized by the three principal Benin breeds, Somba (Supplementary Tables S1 and S4), Borgou (Supplementary Tables S2 and S4) and Lagune (Supplementary Tables S3 and S4). Where available and appropriate, recorded variables included live BW, average daily gain, % of...
population, mature weight, daily milk production, milk fat content, calving rate and the % of castrated males.

**Breed description**
Cattle bred in Benin are composed of *Bos taurus* and *Bos indicus* subgroups. *Bos taurus* are often referred to as 'European' or 'taurine' cattle including similar types from Africa and Asia whereas *B. indicus* have a prominent hump forward of the shoulder and are known as zebu cattle and are of south Asian origin. Locally adapted, *B. taurus* breeds include Lagune (Dwarf West African Shorthorn), Somba (Savanna Shorthorn), Borgou and *N'Dama* cattle. According to Dehoux and Hounsou-Ve (1993), Borgou cattle arose from a cross between West African Shorthorn (*Lagune* and *Somba* cattle in particular) and West African *B. indicus* (mainly White Fulani). With the exception of *N'Dama* cattle which were imported from the Republic of Guinea, *B. taurus* breeds are native to Benin. Outside of Benin, Borgou cattle also exist in the neighboring countries of Togo, Burkina Faso (*Méré* and Nigeria (*Kétéku*)), while Somba cattle are mainly resident to Togo. In West Africa, *Lagune* cattle are principally located in Togo, Ghana and Nigeria. The *B. indicus* subgroup is exotic from West Africa and includes *N’Bororo, White Fulani, Gudali* and *Djilli* (MAEP, 2003). The distribution by breed type of cattle reared in Benin is as follows: Borgou (88%), Lagune (3.7%), Somba (0.3%) and *B. indicus* cattle (7.7%) (Senou et al., 2008; Gbangboche et al., 2011). This distribution illustrates that Borgou cattle are the dominant breed and *B. taurus* are the dominant subgroup accounting for 92% of cattle in Benin.

**Main categories of cattle**
In Benin, cattle are primarily low productivity multi-purpose being used for production of meat; milk and hides as well as for draft power (MAEP, 2003). Meat is by far the most important product derived from cattle, whereas relatively...
few cattle (4%) are used for draft power with only 80 000 head used for this activity (MAEP, 2003). Milking cows represent 15% of the cattle population with an average milk production of 0.5 to 2 l/lactating cow per day (Faculté des Sciences Agronomiques (FSA), 2006). Around 60% of the milk produced by milking cows is consumed by the calf, 20% to 25% is consumed by the farm family in the home and the remaining is sold for human consumption and processing (cheese) (Dehoux and Hounsou-Ve, 1993; FSA, 2006). According to FSA (2006), farm family consumption can reach 75% to 80% during the dry season and during transhumance when the milk production is extremely low. Following IPCC (2006) and taking into account that cows from Benin are multi-purpose and of low productivity, the category ‘Dairy Cow’ as defined in the 2006 IPCC guidelines is not applicable to Benin. Therefore, Benin cattle are categorized as ‘other cattle’ according to IPCC protocols (IPCC, 2006). Each cattle breed was divided into two broad sub-categories namely ‘Growing livestock’ for that part of the population that had yet to reach mature BW and ‘Other Mature livestock’ for those that have achieved mature BW (Supplementary Tables S1 to S3). This approach accounted for the mature age and weight and the reproductive traits of the animal (Supplementary Tables S4 and S5).

Identification of livestock population subcategories. On the whole, subcategories defined were based on estimation of live BW. They included sex, live BW and age structure of the herds (Supplementary Tables S1 to S3). The subcategories of Borgou cattle were obtained by combining the age groups identified by Dehoux and Hounsou-Ve (1993) and Chabi Macco (1992) that categorized the age of different breeds of cattle on the basis of available records and dentition. Data on suckling calves are not presented in Supplementary Tables S1, S2 and S3 as it was assumed that CH₄ emissions were negligible up to weaning, as calves were mainly fed milk until at least 4 months of age (Dehoux and Verhulst, 1994). Indeed, rumen function in calves <3 months and Yₘ for young cattle consuming only milk are minimal with negligible emission of enteric CH₄ (IPCC, 2006).

Live BW and average weight gain per day. Information on the live BW of Lagune cattle in Benin was not available and as result values were adapted from weights recorded for this breed raised in Togo under similar conditions. The live BW and weight gain of 6 to 12-month-old Somba cattle were used as a default for 6 to 12-month-old Lagune cattle as the breeds are very similar. The live BW of 2 to 4-year-old Borgou cattle was obtained from Symoens and Hounsou-Ve (1991) and Chabi Macco (1992). This subcategory corresponds to the subgroup of Borgou cattle aged on the basis of having two to six teeth (Symoens and Hounsou-Ve, 1991). Average live BWs were estimated for all Benin cattle and subcategories of yearlings, mature cows and mature bulls as weighted means of live BWs over Borgou, Somba and Lagune subcategories at 156, 115, 240 and 275 kg, respectively, and compared with the data of the IPCC (2006) and FAO (2000). Data on growth rates for Somba cattle were obtained from Adanléhousi et al. (2003). However, growth rates of other cattle subcategories (Bull Somba 5 to 6 years, Borgou cattle over 1 year, Lagune cattle) were estimated on the basis of live BW and predicted age as reported in Supplementary Tables S1 to S3. Consecutive subcategories in Supplementary Tables S1, S2 and S3, were used to estimate average daily gain as the difference between their weights divided by the difference in ages.

Milk production and fat content. The average daily production of milk for lactating cows (Supplementary Table S4) was calculated by dividing their total annual production by 365 days. The annual milk production in a year was assumed to be equal to the quantity of milk produced per lactation. The milk production from Togo was used as a default data for Lagune cattle. Fat content of milk was estimated as a percentage of milk weight for lactating Borgou and Lagune cows using data from Kora (2005), who estimated the quantity of lipids in milk relative to milk dry matter.

Percentage of females that give birth in a year. Cow fertility or calving rate was estimated as the ratio of calves born during the year to the number of females of breeding age (Supplementary Table S4).

Average amount of work performed per day. Among the breeds raised in Benin, Borgou cattle are most commonly used for draft power. However, this activity is marginal in Benin and little information is available about it. Therefore, draft power was not taken into account in EF estimates.

Feeding situation. An animal’s feeding situation is required to estimate the net energy expended by the animal during the acquisition of feed (IPCC, 2006). It describes the extent to which cattle are stalled fed, grazed or pastured over large geographical areas. In the present study, the feeding situations of other cattle were defined by analyzing farming methods and feeding practices. In Benin, the farming method is generally traditional, which corresponds to minimal-input, low-production extensive systems using natural pastures in open rangeland or crop residues within fields (Goutondji, 2007; Babatounde et al., 2009; Youssao et al., 2013). Approximately 99% of cattle are produced using a traditional farm management system with <1% being produced on ranches or research stations (Hoste et al., 1992). The traditional method is dominated by two village-based systems of utilizing natural pastures namely transhumance and sedimentary systems. The transhumance system predominates (80%) and is characterized by continuously herding cattle across pasture land (Dehoux and Hounsou-Ve, 1993; MAEP, 2003). Under the sedimentary system, livestock are raised in areas of crop cultivation and subsist on crop residues near villages (Dehoux and Verhulst, 1994). The average grazing time of cattle on pasture is estimated at about 8 h per day and distributed as follows: 75% for grazing, 20% for walking, 5%
for rest/rumination and water consumption (Dehoux and Hounso-Ve, 1993). During the dry season, the grazing time averages 10 h, but can range from 8 to 19 h depending on the availability of forage. During the rainy season, it averages 6 h, but ranges from 10 to 17 h depending on terrain and sward density. Cattle on ranches or research stations are raised on small grazing areas using improved management practices. Improved management systems in Benin include supplementation of cattle on natural pastures or those receiving crop residues as well as health and disease management. When not on pasture, herds may be tied in barns or fenced night parks, with shelter for calves. Borgou and Somba cattle are mainly located in the northern part of Benin and are bred under transhumance and sedentary systems while grazing large land areas. Following Aho (Faculty of Agronomic Science of the University Abomey-Calavi (Benin), personal communication) and IPCC guidelines (IPCC, 2006, table 10.5), Borgou and Somba cattle were assumed to be raised on large grazing areas that required considerable energy expenditure for feed acquisition. Lagune cattle are abundant in the southern part of Benin, bred under sedentary conditions and maintained under grazing systems on small natural pastures or fed crop residues, under palm and coconut trees or on fallow land. Following IPCC (2006), Lagune cattle were considered to be maintained mainly in small paddocks and thus only expended modest amounts of energy to acquire feed.

Forages and their digestibility

In Benin, forages mainly include natural pastures and crop residues. Natural pastures include tropical grasses and legumes (Supplementary Table S6) with a dominance of the former and a scarcity of non-woody legumes (Achar et al., 2001). The main crop residues are maize, sorghum, millet, rice, cotton, cowpea and groundnut. During the rainy season, grasses are the principal forages utilized by grazing cattle (Babatoudou et al., 2009), but during the dry season fodder, multi-purpose trees and crop residues are the main feeds. Crop residues account for 70% of the feed available to cattle in the African Sudano-Sahel region (Djenontin et al., 2004). An average value of 54% was used for forage digestibility based on Benin-specific data on grasses and crop residues digestibility from 2013 version of FAO’s Global Livestock Environmental Accounting Model (Gerber et al., 2013). This digestibility value is consistent with that of 55% and 45% to 55% suggested by IPCC (2006) for female females and bulls grazing African forages and ruminants fed low-quality forage (crop by-products and range lands).

Estimation of feed intake per animal subcategory

After assessment, performance and diet data were used to calculate the feed intake for each animal subcategory in terms of gross energy using the equations from IPCC (2006) as presented in Supplementary Table S7. The metabolic function relevant for each livestock category was identified (Figure 1) and the net energy requirements associated with these functions were estimated using relevant performance data. The net energy requirements were summed and combined with the energy availability in feed to estimate the gross energy requirements for each subcategory. The energy availability of the feed was estimated from the feed digestibility and the energy required for growth and maintenance. The reproductive traits of cattle in Supplementary Table S5 were taken into account in the estimation of net energy requirements for metabolic function (maintenance, growth, pregnancy, lactation). The net energy for pregnancy was estimated for heifers that had reached puberty and for cows whereas the net energy for lactation was estimated only for cows with consideration for the yearly calving rate. Data on the gestation length and age at first calving were used to identify cattle age groups from which net energy for pregnancy and lactation were estimated. Mature cattle were considered to be at maintenance and as a consequence the net energy for growth was considered to be zero.

Estimation of enteric CH4 EFs

The enteric CH4 EF was estimated for each subcategory of cattle, and for each breed within B. taurus and all Benin cattle. Considering cattle subcategories, EFs were calculated using the IPCC (2006) equation:

\[
EF = \left(\frac{GE \times Y_m}{100} \times 365\text{ days}\right) / 55.65 \tag{2}
\]

In this equation, \(EF\) is the emission factor (kg CH4/head per year), \(GE\) the gross energy intake (MJ/head per day), \(Y_m\) the methane conversion factor (%), with 55.65 (MJ/kg CH4) being the energy content of CH4, \(Y_m\) was assumed to be 5% for male and 11.9% for female (IPCC (2006) for other cattle grazing or primarily fed low-quality crop residues and by-products.

For each breed, an average EF was estimated as a weighted mean of EFs of its subcategories across its demographic profile. The individual EF estimated for each subcategory of cattle was then multiplied by the associated demographic profiles and summed. The national average EF for B. taurus was calculated by weighting average EFs for breeds on the basis of their national demographic distribution and was assumed representative for all Benin cattle owing to their predominance. EFs were not included for B. indicus cattle types as similar information was not available and they accounted for <8% of the total cattle population. Cattle demographic profiles are presented in Supplementary Tables S1, S2 and S3 and were derived mainly from Dehoux and Hounso-Ve (1993) and Akadiri (1979). The day weighted population mix for cattle aged 0 to 8 months (11.9% for male and 11.9% for female) from Dehoux and Hounso-Ve (1993) and Akadiri (1979) was used as default value for cattle aged 0 to 6 months. The day weighted population mix for Borgou cattle estimated by Dehoux and Hounso-Ve (1993) was used as default value for Somba and Lagune cattle 0 to 12 months.

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Enteric methane emission factors for Benin cattle

Results and discussion

Enteric CH₄ EFs estimated for cattle from Benin are presented in Table 1. They varied with breed and subcategory ranging from 15.0 to 43.6, 16.9 to 46.3 and 24.7 to 64.9 kg CH₄/head per year for subcategories of Lagune, Somba and Borgou cattle, respectively. National average EFs of 24.8, 29.5 and 40.2 kg CH₄/head per year were estimated for Lagune, Somba and Borgou cattle, respectively.

The IPCC (2006) Tier 2 methodology is a function of a number of attributes including live BW, growth rate, feeding practices, gender and productivity (e.g. pregnancy, milk production, work). These parameters are known to influence cattle energy demand and hence enteric CH₄ production, with the level of animal productivity being the most important factor (Yan et al., 2009). Differences in live BW and grazing systems among breeds of cattle contributed to the variation in estimated EFs among cattle breeds and subcategories. This was expected since the productivity of cattle from Benin is low and a large proportion of gross energy intake is used for maintenance which is related to metabolic BW₀.75 (FAO (2000)). The highest EF was observed for Borgou cattle owing to their greater live BW relative to both Somba and Lagune cattle and the fact that they are primarily raised in extensive pasture systems unlike Lagune cattle which are raised under more intensive conditions. The EF for Lagune cattle was lower than that of Somba cattle, which is a reflection of the need for Somba cattle to expend more energy to acquire feed. The national average EF of all Benin cattle was estimated to be 39.5 kg CH₄/head per year, slightly lower (2.0%) than national average EF for Borgou cattle. This observation reflects the fact that Borgou are the prominent cattle breed in Benin and thus are more heavily weighted in the estimation of the average EF for Benin cattle.

The present study reveals the national average EF for cattle from Benin was 27.4% higher than the default EF suggested by IPCC (2006) for other African cattle (Table 2). The default EFs suggested by IPCC (2006) for other cattle (other default EF) from Africa were estimated using Tier 2 methodology and average performance data and feed characteristics reflecting African regional-specific circumstances (IPCC, 2006; annex 10A.1, table 10A.2; Lassey, 2007). Therefore, discrepancies between results from this study and other cattle default EF for Africa may reflect deviations in cattle management practices within Benin as compared with other African regional-specific circumstances. Among subcategories provided by IPCC (2006) for Africa, only young cattle, mature cows and mature bulls were defined for Benin. On the whole, EFs generated by this study for these subcategories were higher than those from IPCC (2006) except for subcategories of young cattle, mature Lagune and mature Somba bulls. National average EFs estimated for Lagune and Somba cattle were 19.9% and 4.8% lower, respectively than for the EF for other cattle from Africa. In contrast, the national average EF for Borgou cattle was 29.6% higher than the African EF default for other cattle. In general, the differences observed between EFs generated by the present study and default EFs may be attributed to discrepancies in Yₐ, demographic profile and growth performance data, in particular live BW and feeding practices (IPCC, 2006, annex 10A.1, table 10A.2). Indeed, the Yₐ value of 7.0% for grazing cattle from tropical Africa (Sejian et al., 2012) used in the present study was higher than the default Yₐ of 6.5% provided by IPCC (2006) for Africa. It is well known that Yₐ is inversely related to forage quality (IPCC, 2006). Lower Yₐ value suggested by IPCC (2006) for Africa may reflect the assumptions associated with temperate forages which are of higher quality and of lower Yₐ. Apart from mature Lagune and mature Somba cattle, the live BWs of cattle

Table 1 Estimated gross energy intake (mj/head per day) and enteric CH₄ EF (kg/head per year) for cattle breeds and subcategories

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>GE</th>
<th>CH₄ EF</th>
<th>Subcategory</th>
<th>GE</th>
<th>CH₄ EF</th>
<th>Subcategory</th>
<th>GE</th>
<th>CH₄ EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
<td>Female 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
<td>Female 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
</tr>
<tr>
<td>Male 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
<td>Male 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
<td>Male 0 to 6 m</td>
<td>NE</td>
<td>0.0</td>
</tr>
<tr>
<td>Female 6 to 12 m</td>
<td>36.8</td>
<td>16.9</td>
<td>Female 6 to 12 m</td>
<td>53.7</td>
<td>24.7</td>
<td>Female 6 to 12 m</td>
<td>32.8</td>
<td>15.0</td>
</tr>
<tr>
<td>Male 6 to 12 m</td>
<td>39.9</td>
<td>18.3</td>
<td>Male 6 to 12 m</td>
<td>58.8</td>
<td>27.0</td>
<td>Male 6 to 12 m</td>
<td>35.1</td>
<td>16.1</td>
</tr>
<tr>
<td>Heifer 1 to 2 y</td>
<td>56.6</td>
<td>26.0</td>
<td>Heifer 1 to 2 y</td>
<td>82.7</td>
<td>38.0</td>
<td>Heifer 1 to 2 y</td>
<td>64.5</td>
<td>29.6</td>
</tr>
<tr>
<td>YB 1 to 2 y</td>
<td>61.2</td>
<td>28.1</td>
<td>YB 1 to 2 y</td>
<td>120.9</td>
<td>55.5</td>
<td>YB 1 to 2 y</td>
<td>66.5</td>
<td>30.5</td>
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<td>40.5</td>
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<td>56.2</td>
<td>25.8</td>
</tr>
<tr>
<td>YB 2 to 3 y</td>
<td>82.3</td>
<td>37.8</td>
<td>YB 2 to 4 y</td>
<td>125.9</td>
<td>57.8</td>
<td>YB 2 to 3 y</td>
<td>62.6</td>
<td>28.7</td>
</tr>
<tr>
<td>Heifer 3 to 4 y</td>
<td>90.3</td>
<td>41.5</td>
<td>MC ≥ 4 y</td>
<td>141.5</td>
<td>64.9</td>
<td>YB 3 to 4 y</td>
<td>92.4</td>
<td>42.4</td>
</tr>
<tr>
<td>YB 3 to 4 y</td>
<td>94.8</td>
<td>43.5</td>
<td>Bull ≥ 4 y</td>
<td>135.5</td>
<td>62.2</td>
<td>Heifer 3 to 4 y</td>
<td>69.2</td>
<td>31.8</td>
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<tr>
<td>Cow 4 to 5 y</td>
<td>100.8</td>
<td>46.3</td>
<td>Average</td>
<td>40.2</td>
<td></td>
<td>MC ≥ 4 y</td>
<td>80.9</td>
<td>37.1</td>
</tr>
<tr>
<td>YB 4 to 5 y</td>
<td>92.2</td>
<td>42.3</td>
<td>−</td>
<td>−</td>
<td>Bull &gt; 4 y</td>
<td>94.9</td>
<td>43.6</td>
<td></td>
</tr>
<tr>
<td>YB 5 to 6 y</td>
<td>94.5</td>
<td>43.4</td>
<td>−</td>
<td>−</td>
<td>Average</td>
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<td></td>
</tr>
<tr>
<td>MC ≥ 5 y</td>
<td>100.9</td>
<td>46.3</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull ≥ 6 y</td>
<td>95.7</td>
<td>43.9</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>29.5</td>
<td></td>
<td>−</td>
<td>−</td>
<td>−</td>
<td>−</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

y = year; m = month; NE = not estimated; GE = gross energy; EF = emission factor; YB = young bull; MC = mature cow.

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subcategories from Benin were higher than the default data reported for cattle from Africa by IPCC (2006). The levels of production of cattle subcategories from Benin were also slightly higher than those suggested by IPCC (2006) for cattle subcategories in Africa. The national average live BWs of young cattle and grazing mature cows from Benin were 1.6 and 1.2 times higher, respectively than those reported for these cattle subcategories in greater Africa (IPCC, 2006). National average EF estimated for mature females grazing in this study was 54.3% higher than that suggested by IPCC (2006) for this cattle category in Africa, mainly due to differences in estimated live BW, milk production and Ym values. The study reveals the national average EF for cattle from Benin was consistent with EF reported by FAO (2000) for young cattle: 16

<table>
<thead>
<tr>
<th>Subcategory</th>
<th>Estimated CH4 EF (Average values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samba cattle</td>
<td>29.5</td>
</tr>
<tr>
<td>Borgou cattle</td>
<td>40.2</td>
</tr>
<tr>
<td>Lagune cattle</td>
<td>24.8</td>
</tr>
<tr>
<td>All MFG</td>
<td>63.3</td>
</tr>
<tr>
<td>SSA cattle</td>
<td>40.1</td>
</tr>
</tbody>
</table>

EF = emission factor; IPCC = Intergovernmental Panel on Climate Change; FAO = Food and Agriculture Organization; MFG = mature females grazing; SSA = Sub-Saharan Africa.

could be as high as ±40%. It would be useful to undertake a detailed uncertainty assessment to know which parameters contribute most significantly to variability in EFs.

Conclusion

This study has revealed that enteric CH4 EF estimated for cattle from Benin using the Tier 2 method of IPCC (2006) offer additional insight into emissions over the IPCC (2006) default EF suggested for cattle categorized as ‘other’ in Africa. The national average EF calculated for Borgou cattle is representative of the EF for bovine species in Benin. The application of the Tier 2 method contained in IPCC (2006) to Benin conditions also illustrates the challenges in developing Benin country-specific EFs stemming from lack of data within defined subcategories of cattle for animal live BW and growth rate. Further research should also focus on the estimation of uncertainties in Tier 2 inputs. The compiled country-specific data and the estimated EF should be beneficial to Benin in the estimation of national GHG inventories and provide FAO with additional information to improve estimates of enteric CH4 emissions from African cattle.

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Supplementary material

To view supplementary material for this article, please visit

References


Enteric methane emission factors for Benin cattle


