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Research Article
Practical Approach for Estimating Enteric Methane in Smallholder Cattle Systems in Southwestern Vietnam

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Abstract

Background and Objective: Accurate estimation of Methane (CH_4) emissions is vital for developing effective mitigation strategies and for national reporting under international climate agreements. The IPCC default emission factors may not account for the characteristics of tropical cattle raised in smallholder systems. This study aimed to evaluate and calibrate empirical models to estimate dry matter intake (DMI) and enteric CH_4 emissions in crossbred Sindhi cattle (*Bos indicus*) under smallholder conditions in the Mekong Delta, Vietnam. **Materials and Methods:** Data were collected from 150 smallholder farms between March, 2024 and March, 2025. Morphometric (heart girth, HG; body length, BL) data, live weight (W), weight gain (G), DMI and energy content (GE, DE, ME, NEm) were recorded. Predicted DMI and CH_4 emission models were assessed using the coefficient of determination (R^2), residual standard deviation (RSD) and t-tests. **Results:** The developed model in Brazil demonstrated the best fit with ($R^2 = 0.68$, RSD = 0.43, $p<0.05$) and was insignificantly ($p>0.05$) different from the actual DMI, followed by a new model ($DMI = -0.297+0.06911\times W^{0.75}+0.867\times C$, $R^2 = 0.68$, RSD = 0.47, $p<0.05$) developed from local data, in which $W = 89.325\times HG^2\times BL$ ($R^2 = 0.98$, RSD = 23.4 and $p<0.05$). The CH_4 estimation models based on tropical/subtropical cattle (Japan and Kaewpila and Sommart) produced significantly ($p<0.05$) higher CH_4 conversion factor (Ym, GEI (%)) values (7.33-7.74%) than the IPCC default (6.5%). Under lipid-supplemented diets, the developed model in Japan more accurately tracked emission reductions than the IPCC. **Conclusion:** The default IPCC parameters tend to underestimate CH_4 emissions in tropical cattle farming systems. The model of the study is suitable for GHG inventories as the IPCC Tier 2 method and, once combined with the developed model in Japan, holds promise for the Tier 3. Further work should incorporate the effects of dietary additives into emission modeling frameworks.

Key words: Enteric methane, dry matter intake, *Bos indicus*, smallholder livestock systems, greenhouse gas inventory, Mekong Delta

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Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Enteric Methane (CH_4) emissions from ruminant fermentation represent one of the main sources of greenhouse gas (GHG) emissions in the livestock sector, particularly in developing countries. According to Chang *et al.*[1], CH_4 from enteric fermentation accounts for over 40% of total GHG emissions in livestock and this proportion can exceed 60% in extensive systems in tropical regions[2]. The increase in atmospheric CH_4 concentration is mainly driven by anthropogenic activities, with livestock being a contributor[3]. Also, Shindell *et al.*[4] emphasized that reducing CH_4 emissions is among the most effective short-term climate mitigation strategies, potentially limiting global warming by up to 0.3°C by 2050. There were many countries that adopted CH_4 control policies for the livestock sector, including Vietnam. With a global warming potential 27-30 times higher than CO_2 over 100 years[5], CH_4 has become a critical target for climate action. In Vietnam, livestock contributes approximately 15-20% total GHG emissions from the agriculture sector, with cattle farming being a significant source[6].

The Mekong Delta (MD) in Southwestern Vietnam is a key region for the agriculture sector, where cattle farming is dominated by smallholder systems using locally available feed resources such as rice straw, natural grasses and other crop residues[7,8]. Crossbred Sindhi cattle (Sindhi×local, *Bos indicus*) are widely raised in MD due to their adaptation to tropical climates; however, productivity remains low and CH_4 emissions from this system have not been adequately assessed using the Intergovernmental Panel on Climate Change (IPCC) default methods. The IPCC Tier 2 method[1] is recommended for national GHG inventories, as it accounts for factors relevant to gross energy intake (GEI) and a CH_4 conversion factor (Ym %) offering improved accuracy over Tier 1. The default Ym value of 6.5±1.0% GEI is primarily based on data from cattle (*Bos taurus*) in temperate regions. Studies in tropical regions have indicated that Ym values for *Bos indicus* are often higher. Hiep *et al.*[9] reported a Ym of 8.48% for crossbred Sindhi cattle in Vietnam, while Kaewpila and Sommart[10] found an average Ym of 8.2±1.7% for *Bos indicus* in Thailand. To apply the Tier 2 in practical settings, various regression models have been developed to estimate dry matter intake (DMI), a critical input for CH_4 calculation. Developed models in Brazil[11], the US[12], Thailand[13], Japan[14] and IPCC[1,8] use variables like live weight (W), weight gain (G), concentrate level (C) and dietary energy indices.

However, most of these models were developed from data in temperate regions and may not be suitable for smallholder tropical cattle in MD[10-15]. They require detailed laboratory inputs, limiting their applicability in smallholder on-farm conditions. Therefore, there is a critical need for a simple, practical and locally adapted tool for estimating CH_4 emissions from smallholder tropical cattle. This study uses survey data from crossbred Sindhi cattle raised by smallholders in Southwestern Vietnam to propose an approach for estimating enteric CH_4 emissions based on the IPCC Tier 2 methodology, contributing to improved GHG inventory quality in Vietnam.

MATERIALS AND METHODS

Ethical consideration: Animal ethics and welfare standards in the study were strictly adhered to, as this study was a field survey. Participating farms complied with the Vietnamese Law on Animal Husbandry (No. 32/2018/QH14), which regulates the treatment and care of livestock.

Survey site: This study was conducted in smallholder cattle farms from March, 2024-2025 across five districts in former Kien Giang Province (9°23'50"-10°32'30"N, 104°26'40"-105°32'40"E; Fig. 1), which is now part of An Giang Province (from 01 July 2025) in Southwestern Vietnam. The surveyed regions exhibit a tropical monsoon climate, characterized by hot and humid conditions. The temperature ranges from 17-37°C, annual precipitation ranges from 1800-2300 mm and relative humidity varies from 78-85%. The rainy season typically spans from April to November and the dry season from December to March, with December being the coldest month[16].

Data collection: A total of 150 smallholder farms raising crossbred Sindhi cattle (Sindhi×local, *Bos indicus*) were surveyed. Each farm selected one or more animals for data collection. In total, 210 individual cattle were recorded for morphometric traits (heart girth, HG; body length, BL), actual W and G. Actual DMI, C, dietary chemical composition and energy indicators (gross energy, GE; digestible energy, DE; metabolizable energy, ME and net energy for maintenance, NEm) were recorded for 96 animals. The animals were randomly selected to represent diverse ages and nutritional statuses to ensure the sample's representativeness of typical smallholder cattle. All measurements were performed following standard procedures. Animal W was measured using large livestock scales and body dimensions were obtained using a numbered measuring tape[18]. The G was calculated from the reported entry weight (obtained through farmer interviews) to the time of the survey. The actual DMI was assessed over a continuous 7-day period by weighing the feed offered each day and subtracting the leftovers from the previous day[19]. Feedstuff

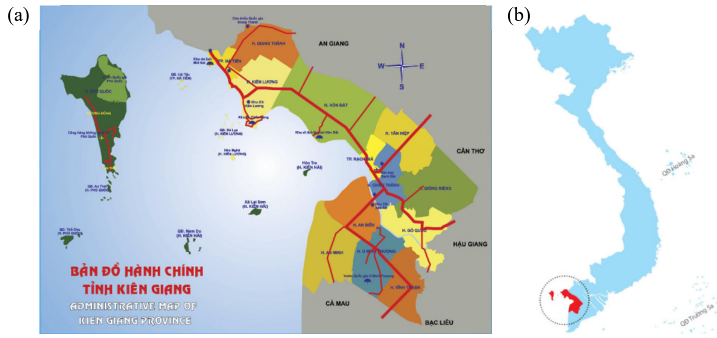

Fig. 1: Surveyed site: (a) Selected districts highlighted with distinct colors: Giang Thanh (dark orange, Northern border with Cambodia); Kien Luong (yellow, Western coastal area); Hon Dat (green, coastal district adjacent to the Gulf of Thailand); Chau Thanh (blue, coastal zone near Rach Gia) and Vinh Thuan (dark orange, Southernmost inland district) and (b) General administrative map of the former Kien Giang Province (redrawn based on van Cuong *et al*.[17]) restructured as of part of An Giang Province from 01 July, 2025

Table 1: Descriptive statistics of key variables in the study

Variable[1]	Mean	Minimum	Maximum	CV[2]
Live weight (kg)	175	74.0	270	18.9
Body length (cm)	129	103	166	9.21
Heart girth (cm)	108	93.0	130	7.11
Dry matter intake (kg/day)	3.33	2.11	5.25	22.6
Weight gain (kg/day)	0.299	0	1.01	62.1
Gross energy (MJ/kg DM)	18.0	17.2	18.7	2.25
Digestible energy (MJ/kg DM)	10.8	9.19	11.5	5.79
Metabolizable energy (MJ/kg DM)	8.99	7.40	9.72	7.01
Net energy for maintenance (MJ/kg DM)	5.39	3.89	6.07	10.9
Organic matter (% DM)	88.5	84.2	90.1	1.61
Crude protein (% DM)	13.1	8.90	22.2	19.8
Ether extract (% DM)	4.20	2.46	5.44	16.1
Neutral detergent fiber (% DM)	62.0	55.3	74.1	7.11
Acid detergent fiber (% DM)	34.3	30.7	41.9	8.07
Concentrate level	0.346	0	0.743	77.4

[1]DM: Dry matter and [2]CV: Coefficient of variation (%)

sampling was also done for analyzing chemical composition according to AOAC[20] and Goering and van Soest[21] and then calculating for the entire diet from the surveyed feedstuff ratios. Dietary energy values (GE, DE and ME) were estimated following IPCC[1,8] and Weiss and Tebbe[22] by following equations:

$$GE = CP \times 0.056 + EE \times 0.094 + (OM - CP - EE) \times 0.042 \quad (1)$$

$$DE = 0.6 \times GE \quad (2)$$

$$ME = 1.01 \times DE - 0.45 \quad (3)$$

$$NEm = 1.37 \times ME - 0.138 \times ME^2 + 0.0105 \times ME^3 - 1.12 \quad (4)$$

Where:

GE = Gross energy
CP = Crude protein
EE = Ether extract
OM = Organic matter
DE = Digestible energy
ME = Metabolizable energy
NEm = Net energy for maintenance

All energy values are expressed in Mcal/kgDM and can be converted to MJ by multiplying by 4.1867. The descriptive statistics of the dataset are in Table 1.

Estimation of live weight: The Schaeffer[23] model was applied to analyze relationships to actual W; the model is:

$$W = 89.325 \times HG^2 \times BL \quad (5)$$

Where:

W = Live weight (kg)
HG = Heart girth (m)
BL = Body length (m)

Estimation of dry matter intake: To estimate DMI, several previously published regression models were selected and compared with actual DMI under smallholder conditions. The evaluated models include those developed in:

Brazil[11]:

$$DMI = -1.303 + 0.0029 \times C - 0.00005 \times C^2 + 0.0843 \times W^{0.75} + 2.243 \times G - 0.271 \times G^2 \quad (6)$$

Japan[14]:

$$DMI = -3.481 + 2.668 \times G + 0.04548 \times W - 0.00007207 \times W^2 + 0.00000003867 \times W^3 \quad (7)$$

Thailand[13]:

$$DMI = 0.02887 \times W - 0.5778 \quad (8)$$

The US[12]:

$$DMI = (0.1493 \times NEm - 0.046 \times NEm^2 - 0.0196) \times SW^2 \quad (9)$$

IPCC[1,8]:

$$DMI = W^{0.75} \times (0.2444 \times NEm - 0.0111 \times NEm - 0.472) / NEm \quad (10)$$

There was a new model derived from endogenous data:

$$DMI = -0.297 + 0.06911 \times W^{0.75} + 0.867 \times C \quad (11)$$

Where:

DMI = Dry matter intake (kg/day)
C = Concentrate level
W = Live weight (kg)
G = Weight gain (kg/day)
ME = Metabolizable energy (Mcal/kg DM)
NEm = Net energy for maintenance (Mcal/kg DM)
SW = Shrunk body weight (= $0.88 \times W^{1.0175}$)

Estimation of enteric methane emissions: To evaluate CH_4 emissions from enteric fermentation, the study employed several widely used models. These models were developed based on dietary and animal characteristics and are suitable for application in diverse livestock systems. The models for predicting CH_4 emission selected in this study developed in Japan[14] based on DMI; by Yan *et al.*[24] based on DMI; Hynes *et al.*[25] based on DMI and C; Yan *et al.*[26] based on DMI and GE; IPCC[1,8] based on DMI and GE; Ellis *et al.*[27] using DMI, ME, neutral detergent fiber (NDF) and C; Kaewpila and Sommart[10] using DMI, GE, DE and ME and other model of Yan *et al.*[26] using DMI, GE, DE, ME, NDF, acid detergent fiber (ADF) and C. Input variables were either measured as described in previous sections.

Data analysis and model validation: All data analyses were conducted using Minitab 21[28]. The descriptive statistics, t-tests and regression analyses were applied. Model validation was performed by key statistical indicators as the residual standard deviation (RSD), the coefficient of determination (R^2) and the significance level (P) in linear regression analysis. A higher R^2 indicates a better model fit to the observed data. A lower RSD reflects higher predictive precision of the model. A model was considered significant when $p<0.05$.

RESULTS AND DISCUSSION

Live weight estimation: The Schaeffer model (Eq. 5) was applied to estimate actual W in 210 crossbred Sindhi cattle across five districts in the Mekong Delta. A strong linear relationship was observed between the morphometric product ($HG^2 \times BL$) and actual W (Fig. 2). The model showed high statistical performance with an $R^2 = 0.981$, RSD = 23.4 and $p<0.05$ (for linear regression with intercept: $R^2 = 0.683$, RSD = 20.9 and $p<0.05$), indicating its strong fit to the dataset.

Live weight estimation: Five DMI prediction models were evaluated using field data in 96 crossbred Sindhi cattle from 150 smallholder farms. The observed average DMI was 3.33 kg/day with a CV of 22.6%. Among the tested models, the developed model in Brazil[11] (3.32 kg/day) provided the closest relationship ($R^2 = 0.68$) to the observed data (3.33 kg/day) and an insignificant difference ($p>0.05$). Other models, Japan[14], Thailand[13], the US[12] and IPCC[1,8], overestimated DMI, with significant differences ($p<0.05$). Regression analysis (Fig. 3) confirmed that the Brazil[11] model had the highest $R^2 = 0.68$, the lowest RSD = 0.43 and $p<0.05$, followed by the Japan[14] model ($R^2 = 0.62$), the US[12] ($R^2 = 0.54$), IPCC[1,8] ($R^2 = 0.48$) and Thailand[13] ($R^2 = 0.42$). Table 2 summarizes the model comparison results.

A multiple regression model was also developed from the local dataset as Eq. 11 (Fig. 4). This model achieved an $R^2 = 0.68$; RSD = 0.47 and $p<0.05$, indicating comparable performance to the Brazil[11] model (Eq. 6) with fewer input variables.

Estimation of the methane conversion factor: Eight models were used to estimate the Ym, defined as the proportion of GEI converted into CH_4. The results for crossbred Sindhi cattle

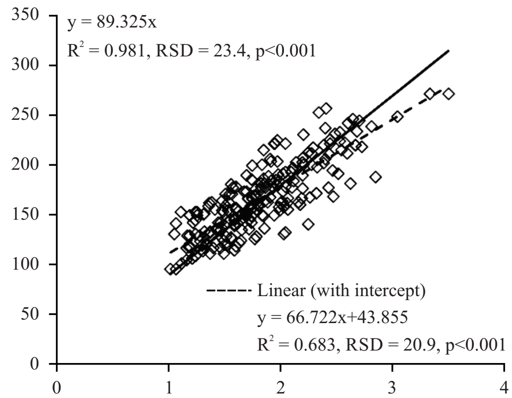

Fig. 2: Relationship between body morphometrics ($x = HG^2 \times BL$, m^3) and live weight (y, kg) of cattle

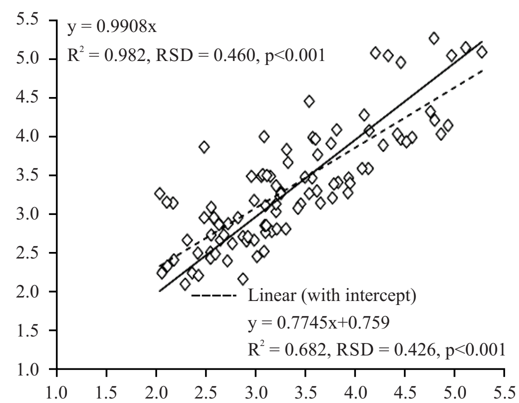

Fig. 3: Linear relationship between actual (y, kg/day) and predicted DMI (x, kg/day) by the Brazil[11] model

Table 2: Comparison between observed DMI (kg/day) and model-predicted values

	Pairwise comparison[2]			Regression analysis[3]			
Model[1]	Mean±CV	SD	P	Regression model	RSD	P	R^2
Observed DMI	3.33±22.6	-	-	-	-	-	-
Brazil[11]	3.32±24.1	0.047	0.820	y = 0.759+0.7745x	0.426	<0.001	0.68
Japan[14]	3.10±32.6	0.064	0.001	y = 1.511+0.5859x	0.463	<0.001	0.62
Thailand[13]	4.00±22.9	0.073	<0.001	y = 1.216+0.5280x	0.578	<0.001	0.42
The US[12]	4.13±16.9	0.054	<0.001	y = 0.051+0.7928x	0.511	<0.001	0.54
IPCC[1,8]	4.32±15.2	0.057	<0.001	y = -0.108+0.796x	0.542	<0.001	0.48

[1]DMI: Dry matter intake; [2]CV: Coefficient of variation (%), SD: Standard error of t-test, P: Significant level of t-test; [3]RSD: Residual standard deviation, R^2: Coefficient of determination and P: Significant level of regression

in the Mekong Delta showed a range of Ym values from 6.50 to 8.39%, depending on the model applied. The results are summarized in Table 3.

Statistical analysis revealed significant differences among models (p<0.05). The IPCC[1,8] model provided the lowest Ym value (6.5%), while the model by Yan *et al.*[26] produced the highest value (8.39%) with the lowest CV = 1.62%, suggesting high statistical stability. Models based on tropical/subtropical cattle data, such as Kaewpila and Sommart[10] and Japan[14], yielded Ym values above 7.5%.

Estimation of methane emissions under dietary lipid supplementation: To assess the predictive performance of CH_4 estimation models under lipid-supplemented diets, data from Thu and Đông[29] (basal diets of rice straw plus concentrate) and Hiep *et al.*[9] (basal diets of NaOH-treated rice straw plus cassava leaves) were used. These studies included coconut oil (0-3%) and sunflower oil (1.5-6%) for crossbred Sindhi cattle. Measured CH_4 emissions were compared with models from Japan[14] and IPCC[1,8] as in Table 4.

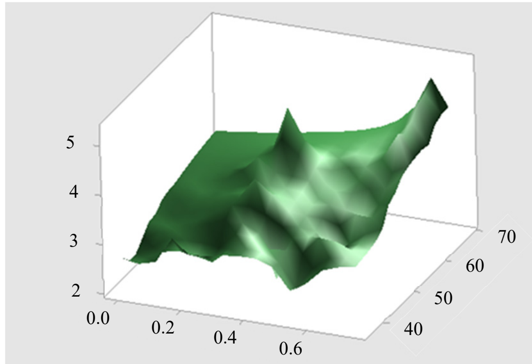

Fig. 4: Multiple regression between concentrate level (x = C), live weight (z = $W^{0.75}$, $kg^{0.75}$) and dry matter intake (y = DMI, kg/day): $DMI = - 0.297+0.06911\times W^{0.75}+0.867\times C$ ($R^2 = 0.68$, RSD = 0.47 and $p<0.001$)

Table 3: Estimated methane conversion factor (Ym %) across models

Model sources	Mean	Minimum	Maximum	CV[2]
Japan[14]	7.57[b]	7.0	8.0	2.53
Yan *et al.*[24]	7.10[d]	5.8	8.2	6.64
Hynes *et al.*[25]	6.84[e]	6.0	7.3	4.93
Yan *et al.*[26]	8.39[a]	8.1	8.7	1.62
IPCC[1,8]	6.50[f]	-	-	1.00
Ellis *et al.*[27]	6.73[ef]	4.5	9.8	22.5
Kaewpila and Sommart[10]	7.74[ab]	4.9	12.2	23.3
Yan *et al.*[26]	7.33[c]	5.2	7.8	9.23

[1]Means within a column with different letter superscripts differ significantly ($p<0.05$) and [2]CV: Coefficient of variation (%)

Table 4: Enteric methane (L/day) emissions under dietary oil supplementation

			Estimated CH_4	
Oil supplementation	DMI (kg/day)	Measured CH_4	Japan[14]	IPCC[1,8]
0% coconut oil[1]	4.80	164	171	159
1% coconut oil[1]	4.61	146	163	154
2% coconut oil[1]	4.49	135	158	150
3% coconut oil[1]	4.15	110	144	140
Mean	4.51	139	159	151
P (t-test)	-	-	0.178	0.377
1.5% sunflower oil[2]	5.15	184	185	159
3% sunflower oil[2]	5.07	127	182	155
5% sunflower oil[2]	5.07	154	182	151
6% sunflower oil[2]	4.93	129	176	142
Mean	5.06	149	181	152
P (t-test)	-	-	0.090	0.827

[1]Thu and Dong[28] and [2]Hiep *et al.*[9]

Without and low oil supplementation, both Japan[14] and IPCC[1,8] models produced CH_4 estimates that were not significantly different from measured values ($p>0.05$). As oil levels increased, measured CH_4 emissions declined, while both models overestimated CH_4 output. The Japan[14] model showed a closer agreement to observed reductions, particularly at low-to-moderate inclusion rates (0-1.5%).

The application of the Schaeffer[23] model (Eq. 5) in this study demonstrated a highly accurate estimation of W in crossbred Sindhi cattle, with $R^2 = 0.98$, RSD = 23.4 kg, $p<0.05$. The strong linear relationship between morphometric indices and actual W validates this model in smallholder conditions where weighing facilities are limited. The findings are consistent with previous studies emphasizing the predictive power of morphometrics in cattle. In Brazil, Mota *et al.*[30] reported a correlation r = 0.93 between HG and W for Holstein×Zebu. Rashid *et al.*[18] found r = 0.96 in F1 Brahman crossbreds, with the equation $Y = 4.07\times HG-356$, explaining 93% W variation. Lukuyu *et al.*[31] reported an $R^2 = 0.71$ for the model $W = 4.277\times HG-393.13$ in crossbred dairy cows in Kenya. In Senegal, Tebug *et al.*[32] developed a model $W = 4.81\times HG-437.52$ with $R^2 = 0.85$. These affirm that morphometrics is the most reliable predictor of W in tropical cattle. These findings align with the current study, in which crossbred Sindhi cattle show similarities with those (*Bos indicus*) in Africa and South Asia. The increased accuracy in observation of Rashid *et al.*[18] in mature cattle was identified by the correlation between HG and W with each age. In practical terms, the Schaeffer[23] model offers a low-cost, rapid estimation suitable for applications in smallholders' on-farm conditions. When combined with measurement tools based on biometric measurements such as HG and BL (e.g., Schaeffer formula)[33], this approach enhances the feasibility of application in GHG inventory by the IPCC Tier 2 method in smallholder cattle farming systems.

Among DMI prediction models, the developed model in Brazil[11] demonstrated the highest accuracy (R^2 = 0.68; RSD = 0.43; $p<0.05$), showing no significant difference ($p>0.05$) from observed values. The inclusion of relevant predictors, such as W, C and G, likely contributed to its accuracy. The Japan[14] model, despite using fewer input variables (W and G), showed relatively high predictive capacity (R^2 = 0.62; RSD = 0.43; $p<0.05$), but its predictive value is significantly ($p<0.05$) higher than the actual. These models were originally developed from tropical/subtropical cattle (*Bos indicus*), which are similar to Sindhi crossbreed cattle in Vietnam. Other models, such as in the US[12], IPCC[1,8], though theoretically robust, overestimated DMI under field conditions ($p<0.05$). These models were primarily developed from temperate cattle (*Bos taurus*), which may not be readily available or fully applicable in cattle farming systems of tropical smallholders. The locally derived regression model in this study (Eq. 11), based on W and C, also achieved strong performance (R^2 = 0.68; RSD = 0.47; $p<0.05$). It can predict DMI based on cattle morphometrics (HG, BL) and C and makes it a feasible tool for field use, especially when supported by farmer reports. This is particularly relevant for GHG inventory efforts where direct measurements are impractical. Overall, these findings underscore the importance of using DMI predictive models tailored to specific regional breeds as a critical factor to enhance the accuracy of the IPCC Tier 2 inventory.

The Ym is a core parameter in the IPCC Tier 2 method, representing the proportion of GEI lost as CH_4 during enteric fermentation. In this study, all evaluated models produced enteric CH_4 emissions higher than the IPCC's Ym default of 6.5%, with significant differences ($p<0.05$). The highest estimate was obtained from the model of Yan *et al.*[26] (8.39%), while the lowest was the IPCC default itself. The Kaewpila and Sommart (Ym, % GEI = 37.70+19.71 × DE/GE-50.70 × ME/DE)[10] and Japan (CH_4, l/day = -17.766+42.793 × DMI-0.849 × DMI^2)[14] models, both derived from tropical/subtropical cattle (*Bos indicus*), produced Ym values of 7.53-7.74%. Previous local studies of Hiep *et al.*[9] and Thu and Đông[29] also reported Ym values exceeding 6.5%, supporting the inadequacy of the IPCC default for tropical cattle farming systems. This highlights the importance of regional-specific Ym in CH_4 emission estimation. While the IPCC default provides a globally consistent baseline, its continued use in Vietnam's Tier 2 inventory could lead to underreporting of CH_4 emissions. Overall, the results emphasize the necessity of replacing IPCC default values. Refinement with regional Ym derived from local cattle farming systems would improve the accuracy of national GHG inventories in Southeast Asia. For practically applying these models in Vietnam, the dietary chemical composition can be referenced from Huyen *et al.*[34] and energy values are estimated following Eq. 1-3[1,8,22].

The use of dietary lipids as a CH_4 mitigation strategy is well supported in much literature[2,35-37]. In this study, actual measurements confirmed that CH_4 emissions declined as oil inclusion levels increased, particularly beyond 2%. Both developed models in Japan[14] and IPCC[1,8] overestimated CH_4 emissions under oil-supplemented diets, indicating that neither model accounts for the enteric CH_4-suppressing effect of dietary additives. The Japan[14] model more accurately reflected the downward trend in emissions at low-to-moderate oil levels (0-1.5%), whereas the IPCC[1,8] model estimates remained relatively static. This suggests that the Japan[14] model has greater sensitivity, making it more adaptable to real-world diet changes, causing DMI variation, even though it does not include additives as an input variable. The overestimation observed at $\geq$3% oil inclusion shows that current models lose accuracy with dietary additives. The lack of an additive-adjustment factor in models limits their predictive accuracy in scenarios where dietary additive levels significantly alter ruminal fermentation. These findings highlight the need for developing or modifying CH_4 estimation models that need to integrate additive factors as input variables. This is particularly relevant as more smallholder and commercial systems begin incorporating additives to meet national mitigation targets. Incorporating an additive correction coefficient may improve prediction accuracy, hopefully without increasing model complexity. Improving models according to additive inclusion will support more precise GHG inventory reporting.

CONCLUSION

The results of this study indicate that the current IPCC model tends to underestimate enteric CH_4 emissions when applied to Sindhi crossbred cattle (*Bos indicus*) widely reared in smallholder systems in the MD, Vietnam. The developed model in Brazil and this study yielded DMI estimates aligned with empirical data, suggesting them for application in GHG inventories as the IPCC Tier 2 method. The CH_4 estimation model developed in Japan, requiring only DMI as input, shows considerable potential for development into a Tier 3. However, further validation and calibration studies are necessary, based on datasets that reflect the specific farming conditions. These efforts will be crucial for the development of a Tier 3 tool to enhance the quality of the national GHG inventory in tracking updated nationally determined contributions under the Paris Agreement.

SIGNIFICANCE STATEMENT

The study represents one of the first comprehensive evaluations of predicting DMI and enteric CH_4 emissions in tropical cattle (*Bos indicus*) widely raised by smallholders in the Mekong Delta, Vietnam. The study shows that the model in this study is practical for GHG inventories from tropical cattle in smallholders as the IPCC Tier 2 method and once combined with the developed model in Japan, it has high potential for the on-farm GHG inventory as the IPCC Tier 3.

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