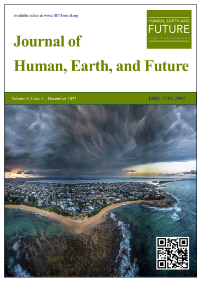
Available online at www.HEFJournal.org

Journal of
Human, Earth, and Future

ISSN: 2785-2997

Vol. 6, No. 4, December, 2025



Country-Specific Data on Buffalo Manure Management Practices Improves Estimates of Manure Methane Emissions

Estella P. Valiente [1*], Che Lean C. Cabico [1], Andreas Wilkes [2], Joshua P. Nacino [1], Janine D. Pascua [1], Jocelyn T. Nueda [1], Danica M. Aguilar [1], Faith Jovie P. Burgonio [1], Charity I. Castillo [1], Ann-Sherly R. Dugyon [1], Phoebe Lyndia T. Llantada [1]

[1] *Philippine Carabao Center National Headquarter and Genepool, Science City of Muñoz, Nueva Ecija, 3120, Philippnes.*

[2] *New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC), Palmerston North 4442, New Zealand.*

Received 13 June 2025; Revised 15 October 2025; Accepted 02 November 2025; Published 01 December 2025

Abstract

This study addressed data gaps in manure management systems (MMS) for buffalo in the Philippines to improve the national greenhouse gas (GHG) inventory of methane (CH_4) emissions. A total of 772 buffalo farmers were surveyed through face-to-face interviews to document their socio-economic and farm profiles as well as fraction of manure managed in each MMS. These data are essential inputs for developing country-specific CH_4 emission factors (EF) following the Tier 2 method of the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Findings revealed notable differences in the socio-economic and farm profiles of dairy versus draft buffalo farmers. The fraction of manure managed in each MMS also varied by farm scale. Smallholder farms primarily left manure to decompose in the grazing area (58.30%), applied manure to crops (30.45%) or managed it in solid storage (6.31%). Semi-commercial farms employed more diverse systems, including crop application (47.51%), solid storage (11.65%) and composting (3.24%), in addition to leaving manure in the grazing area (32.46%). Comparison with the Tier 1 MMS assumptions showed that Tier 1 default values failed to fully capture the range of MMS observed in the field. The Tier 2 EF estimated in this study was 8-10% higher than the Tier 1 EF for smallholder systems, and substantially higher by 39-92% for semi-commercial and commercial farms, exceeding the IPCC Tier 1 default EF uncertainty margins. This study highlights the critical role of country-specific data in enhancing the accuracy of GHG emission estimates, thereby supporting the development of more effective and informed mitigation strategies. Key recommendations include institutionalizing the Tier 2 method in national inventory compilation systems, and promoting improved manure management on smallholder farms through targeted training and extension programs.

Keywords: Buffalo; Manure Management System; Methane Emissions; Emission Factor.

1. Introduction

In response to the global climate change crisis, in 2015, 195 parties of the United Nations Framework Convention on Climate Change (UNFCCC) signed the Paris Agreement, which aims to significantly cut global greenhouse gas (GHG) emissions so as to limit the global temperature increase in this century to well below 2 degrees Celsius

* Corresponding author: estella.valiente@pcc.gov.ph

http://dx.doi.org/10.28991/HEF-2025-06-04-05

compared to pre-industrial times, while striving to limit the increase to 1.5 degrees Celsius [1]. Under the Paris Agreement, all parties – including both developed and developing countries – commit to reduce GHG emissions and to strengthen those commitments over time. The commitment of each nation was stipulated in their so-called Nationally Determined Contributions (NDCs) which outline the targets of each country for curbing emissions, including through the preservation of carbon sinks, from 2025 to 2030. A notable component of the Paris Agreement is that it encourages developing countries, including the Philippines, to contribute to global emission reductions, and obliges the developed nations to assist developing nations in their climate mitigation and adaptation efforts. The agreement also created a framework for transparent monitoring and reporting, and for progressive strengthening of countries' individual and collective climate goals [2]. Expanding the range of sectors included in NDCs, identifying implementation mechanisms, and increasing emission reduction commitments are all potential ways to strengthen the ambition of a country's climate commitments [3].

The national GHG inventory is a key tool used by nations to report their progress towards their climate goals. Decisions pursuant to the Paris Agreement recognize that national GHG inventories will be continuously improved over time [4]. One important way to improve inventories is to use more advanced (i.e., higher tier) methods to estimate GHG emissions. The Tier 1 method is the most basic method, requiring only information on animal populations and a region-wide default emission factor (EF) obtained from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories [5, 6]. However, because regional default emission factors may not accurately represent country-specific conditions, the uncertainty associated with Tier 1 EFs is relatively high (±30%). Furthermore, since it assumes fixed emission factors, the only way to reduce livestock emissions is by reducing animal numbers, which is an impractical strategy for many producers. As such, the Tier 1 method is unable to capture a country's unique conditions or trends over time other than changes in total animal numbers. Thus, this method is not useful for policymaking or for identifying mitigation options in the livestock sector [7].

The Tier 2 method is more accurate but more complex as it uses country-specific emission factors calculated using country-specific data on animal performance and management. It requires country-specific data on populations of animal sub-categories that differ in performance or management, and on the gross energy intake, feed quality and manure management systems in each animal sub-population [5]. The Tier 2 method can reflect the effect of different management practices and change in the structure of the livestock sector on GHG emissions, and is more useful for identifying mitigation options, setting policy goals, and measuring the effects of policy implementation on GHG emissions [7]. Inventory improvement can therefore support countries to enhance GHG reduction ambition in line with the Paris Agreement. The Philippines, as one of the signatories to the agreement, has committed to reduce GHG emissions by 75% compared to business–as-usual scenario emissions by 2030. Most (72.29%) of the reduction, however, will be conditional on receiving support from developed countries, while 2.71% of the target is unconditional to be achieved using the country's own resources [8]. However, reducing GHG emissions from manure management was not explicitly considered when the NDC targets were elaborated. The absence of country-specific data to characterize current manure management practices, due to limited financial resources and technical capabilities, was one major barrier to including policies, measures or targets for manure management in the country's NDC. According to the IPCC Guidelines, emission sources that contribute to 95% of total national GHG emissions (known as 'key categories') should be estimated using the Tier 2 method [5]. The Philippines' latest official national GHG inventory, which used the Tier 1 method, identified methane and nitrous oxide emissions from manure management as key categories [9]. The inventory suggests that, after swine, buffalo make the second largest contribution to manure management methane emissions in the Philippines. Having identified manure management emissions from buffalo as a key category, the Department of Agriculture Climate Resilient Agriculture Office delegated the Philippine Carabao Center (PCC), the agency mandated to propagate, conserve and promote buffalo in the Philippines, to improve the national GHG emissions inventory for the buffalo sector.

A literature review identified few relevant previous studies in the Philippines. One study reported buffalo manure management practices by a small sample of dairy buffalo farmers in two towns in Nueva Ecija province [10]. However, the study covered dairy buffalo farmers only, whereas the majority of buffalo in the Philippines are draft buffalo, thus providing an insufficiently representative basis for estimating manure management practices at national level. Another study quantified GHG emissions from water buffalo by age category in Central Aurora, Philippines, but used the Tier 1 method that does not consider local manure management practices [11]. No published literature was identified that documents the application of the Tier 2 methodology for GHG estimation in livestock in the Philippines, within the existing body of research, hence, this research was conducted. Some studies from South and elsewhere in Southeast Asia have reported experimental measurements of methane emissions from buffalo manure [12-14], but the paucity of data for Southeast Asia, and the Philippines in particular, is confirmed by recent global reviews [15, 16]. There are also few studies of buffalo manure management practices [17, 18], and global, regional or national studies using the IPCC Tier 2 method have relied significantly on the default manure management assumptions in the IPCC Guidelines. Therefore, this study aimed to improve buffalo manure management methane emission estimates by filling existing data gaps on manure management systems used buffalo farmers in the Philippines. Specifically, it aimed to:

(1) Document the socioeconomic and farm profile of draft and dairy buffalo farmers in the Philippines;

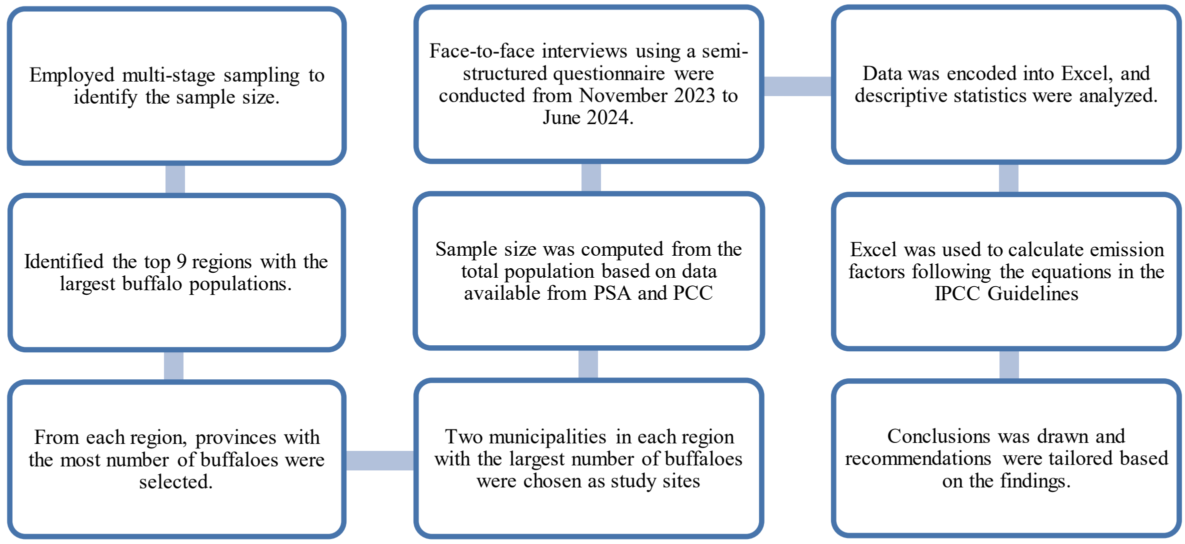
(2) Identify the manure management systems practiced by both dairy and draft buffalo farmers, and estimate the proportion of manure handled in each system; and

(3) Estimate the methane emission factor (EF) using the Tier 2 methodology, based on country-specific data on manure management systems.

The following section describes the study's data sources and methods. Section 3 presents the key findings, including the socio-economic and farm characteristics of buffalo farmers, their manure management practices, and the computed Tier 2 country-specific emission factors, which are also compared with the Tier 1 emission factor. The paper concludes by summarizing the key findings and providing insights and policy recommendations aimed at improving the accuracy of greenhouse gas inventories and supporting the advancement of sustainable manure management practices in the Philippines.

2. Materials and Methods

The methodological framework employed to realize the objectives of this study is presented in Figure 1, which summarizes the sequential steps conducted in this study.



Note: PSA is Philippine Statistical Authority; PCC is Philippine Carabao Center; IPCC is Intergovernmental Panel on Climate Change.

Figure 1. Flowchart illustrating the sequential methodological steps undertaken to realize the objectives of the study

2.1. Research Sites and Sample Size

The survey was conducted in the nine regions in the Philippines with the greatest number of buffaloes (Figure 2). Data on buffalo populations from the Philippine Statistics Authority (PSA) and the Operations Unit of the Philippine Carabao Center were used as the basis for setting the sampling frame. The total population was categorized based on the primary use of buffalo, i.e. draft or dairy, because the management system differs between these two categories.

The sample size for each category was determined using Slovin's formula at 5% margin of error and 95% level of confidence. The computed sample size with 100% response rate for the dairy buffalo category was 353 and for the draft type was 400. The samples for each buffalo category were allocated in proportion to the inventory of buffaloes in each identified study site. Multi-stage sampling was employed such that for each region, the province with the greatest number of buffaloes was selected as representative of the region. In each selected province, the top 2 municipalities with the greatest number of buffaloes were selected, and the village in each municipality with the greatest number of buffaloes was selected to serve as the site where respondents were sampled.

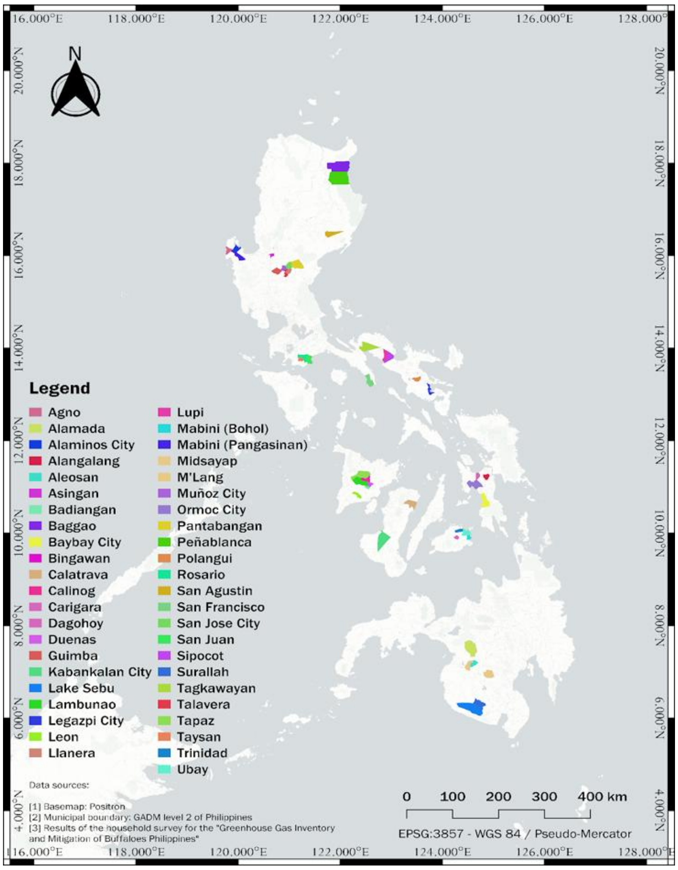


Figure 2. Location of the sites where dairy and draft buffalo farmers were interviewed.

Within each village, purposive sampling was applied because the village council leader (locally termed 'Barangay Captain') identified the farmers who were invited to join the interview on an agreed schedule in the village council office. The buffalo farmers who attended the village council office were interviewed. Although it was emphasized in the communication letter to the Barangay Captain prior the interview to invite farmers with different socioeconomic backgrounds and farm profiles, where possible, so as to minimize bias, selection by the Barangay Captain of more cooperative, prominent, or accessible farmers may have occurred (Table 1).

Table 1. Number of interviewed dairy and draft buffalo farmers per region, Philippines, 2024

Region	Number of Respondents		
	Dairy	Draft	Total
Region 1 (Ilocos)	28	32	60
Region 2 (Cagayan Valley)	52	64	116
Region 3 (Central Luzon)	42	48	90
Region 4 (CALABARZON)	32	36	68
Region 5 (Bicol)	56	65	121
Region 6 (Western Visayas)	49	54	103
Region 7 (Central Visayas)	39	44	83
Region 8 (Eastern Visayas)	31	36	67
Region 12 (SOCCSKSARGEN)	20	44	64
Total	**349**	**423**	**772**

2.2. Data Collection

In compliance with the Data Privacy Act of 2012, the data collection involved first asking the respondents for their consent to be interviewed. The objectives and expected duration of the interview were explained to the respondents. The respondents were then asked if they are willing to be interviewed or not. If they were willing, the interview proceeded. A 100% response rate was achieved in this survey. The anonymity of the respondents was maintained throughout the entire research process.

Data gathering was done through individual in-person face-to-face interviews using a semi-structured questionnaire, one for draft buffalo farmers and one for dairy buffalo farmers. Both questionnaires were designed to capture the management system used by buffalo farmers according to farm category (i.e., smallholder or semi-commercial farm). Following official definitions [19], smallholder farms are farms tending not more than 5 caracows; semi-commercial farms are farms tending 6 to 50 caracows; and commercial farms are farms tending more than 50 caracows.

The questionnaire included the following data items:

1. Informed Consent: In compliance with the Data Privacy Act of 2012, ensuring participant confidentiality and voluntary participation.
2. Farmer's Socio-Demographic Profile: Information on the farmer's age, education, experience, and other relevant personal characteristics.
3. Farm Information: Details such as farm location, the number and classification of buffaloes, and other farm-specific data.
4. Management System: Information on the type of management system employed, such as whether the system is confinement-based or grazing-based.
5. Manure Management System: Data on the practices and methods employed for manure management on the farm including the fraction of manure managed within each system.

The questionnaire was written in English language with translation in the national language of the Philippines which is Filipino. The questionnaire was first pre-tested with 15 farmers to ensure its validity and reliability as well as to assess the time needed to administer the questionnaire.

Data collection was undertaken by hired research assistants and enumerators from November 2023 to June 2024. Prior to data collection, the hired research assistants and enumerators were trained to ensure uniform understanding of concepts and proper implementation of survey procedures. The documented manure management practices of buffalo farmers were translated into the terminology used in the 2006 IPCC Guidelines [5].

2.3 Data Analysis

The gathered data were encoded and analyzed in a Microsoft Excel spreadsheet, which was manually programmed and customized to the condition of each surveyed farm, using descriptive statistics such as count, mean, and percentage. To determine the fraction of manure managed in each manure management system (MMS), the annual average mass was considered. Since farmers employ multiple MMS throughout the manure's lifecycle, the duration (in days) that manure remains in each system was accounted for.

Data on manure management, work hours and other required country-specific parameters, such as weight, weight gain, pregnancy rate, percentage of lactating cows, milk production, lactation length, milk fat content, diet digestible energy and crude protein content including temperature were retrieved from various literature sources and reports, and entered into a separate Excel spreadsheet. This spreadsheet was programmed using formulas from the 2006 IPCC Guidelines to calculate volatile solid excretion and the manure management methane emission factor. The results are presented in tables and graphs for clarity and ease of interpretation.

3. Results and Discussion

3.1. Socio-Demographic and Farm Profile of the Buffalo Farmers

The socio-demographic profile of each buffalo farmer was gathered along with the characteristics of their farm. The relationship between farm characteristics and a farmer's capability to adopt mitigation or technological practices is multifaceted, influenced by various factors such as farm size, access to resources and farmer demographics. Understanding these relationships can enhance the effectiveness of outreach and policy initiatives aimed at promoting sustainable agricultural practices [20]. The data gathered may serve as a benchmark guide on the capabilities of farmers in different farm types to adopt various adaptation and mitigation technologies or practices.

Table 2 shows the socio-demographic profile of the farmer-respondents categorized as dairy buffalo farmers and draft buffalo farmers. Most of the farmer-respondents were male (78%), while a minority were female (22%). There was a higher percentage of male dairy buffalo farmers (81%) compared to draft buffalo farmers (76%). This can be attributed to the fact that dairy buffalo farming requires strenuous activities such as gathering of feed, milking and feeding, which are commonly performed by male farmers. Generally, most (85%) farmers were married, while very few were single (8%), living with their partner (4%), widowed (2%) or separated (1%).

Table 2. Socio-demographic characteristics of buffalo farmers in the Philippines, 2024

Particulars	Dairy		Draft		All	
	Count (n=349)	%	Count (n=423)	%	Count (n=772)	%
Sex						
Male	283	81	321	76	604	78
Female	66	19	102	24	168	22
Civil status						
Married	292	84	366	87	658	85
Single	30	9	28	7	58	8
Live-in	18	5	13	3	31	4
Widowed	4	1	14	3	18	2
Separated	5	1	2	0.5	7	1
Educational attainment						
High School graduate	113	32	102	24	215	28
Elementary graduate	53	15	121	29	174	23
High School level	37	11	61	14	98	13
Elementary level	25	7	71	17	96	12
College graduate	50	14	23	5	73	9
College level	34	10	27	6	61	8
Vocational Graduate	31	9	11	3	42	5
Vocational level	5	1	3	1	8	1
None	-	-	4	1	4	1
ALS completer	1	0.3	-	-	1	0.1
Mean Age	48		50		49	
Family size						
4-6 family members	197	56	223	53	420	54
3 family members and below	102	29	121	29	223	29
7-9 family members	45	13	66	16	111	14
10 family members and above	4	1	10	2	14	2
Mean Family Size	4.84		4.98		4.92	
Membership in agricultural organizations						
Cooperative	252	71	64	15	316	41
None	56	16	236	56	292	38
Association	45	13	124	29	169	22

The educational attainment among the respondents may be considered moderate to low. Very few had graduated from college (9%), reached college level (8%), or taken vocational courses (5%). Nevertheless, a considerable percentage (28%) had finished high school, although a few (23%) were only able to finish elementary school. One out of ten of the farmer-respondents had reached high school (13%) or elementary school (12%), but were not able to finish their schooling for various reasons.

The average age of dairy buffalo farmers was 48 years old, while for draft buffalo farmers, the average was 50 years old. Both types of farmer were thus on average middle-aged but still in the productive stage of their lives. Family size for the majority of the farmers (54%) was between 4 and 6 members, whereas 29% had a family size of less than 4 members. On average, the family size of the respondents was 5 which coincides with the average national household size in the Philippines.

Most (84%) of the dairy buffalo farmers were members of cooperatives or associations, whereas only 41% of draft buffalo farmers were affiliated with agricultural organizations. In the Philippines, cooperatives and associations serve as the most accessible, practical and effective channels for introducing new technologies or practices.

3.2. Farm Profile

Table 3 summarizes the farm characteristics of the dairy and draft buffalo farmer-respondents. Generally, manure management systems are closely related to other farm features, such as the availability of animal housing or pens. Most of the farmers (73%), particularly draft buffalo farmers, lack proper housing for their animals. It is common practice to let the buffaloes graze freely and tether them under a tree near the house or on the farm during the night or during the hottest part of the day. By contrast, a significant portion (44%) of dairy buffalo farmers have constructed animal pens, most of which (89%) feature cement flooring. This is in alignment with the PCC guidelines, which emphasize the importance of proper housing to optimize dairy production.

Dairy farms were also more likely to have designated forage areas (86%), with Napier grass being the predominant forage type (90%), which is in line with the nutritional requirements for enhancing milk production [21]. Conversely, draft buffalo farms rely less on cultivated forage. Regarding water resources, most dairy farmers (74%) depend on wells for consistent water supply, and less on natural water bodies, public water systems or irrigation. By contrast, draft buffalo farmers rely on rainfall (52%), irrigation (36%) and natural water bodies (7%) as the main water source. This may indicate the potential relevance of improving water resource management for productive and sustainable buffalo production.

In terms of herd composition, the study found that the majority of dairy buffalo farmers keep crossbred (60%) and riverine buffaloes (33%). This is because of the higher milk yields of these breeds [22] compared to the Philippine native breed, which draft buffalo farms mainly raise (73%). Moreover, 41% of draft buffalo farms were located in lowland areas, which are well-suited for grazing practices, while 59% were situated in moderately hilly or upland areas, indicating the native breed's adaptability to varied terrain [23].

Table 3. Farm characteristics of buffalo farmers in the Philippines, 2024

Particulars	Dairy		Draft		All	
	Count (n=349)	%	Count (n=423)	%	Count (n=772)	%
Availability of animal pen						
Not available	197	56	365	86	562	73
Available	152	44	58	14	210	27
Flooring type of animal pen						
Cement	175	89	-	-	175	89
Soil	21	11	-	-	21	11
Gravel	1	1	-	-	1	1
Area of animal pen (m^2)	86	-	-	-	-	-
Crop Area (ha)	2.10	-	1.95	-	2.02	-
Water source*						
Well	145	74	5	1	150	19
Natural body of water	24	12	31	7	55	7
Public water system	19	10	-	-	19	2
Irrigation	5	3	149	36	154	20
Water impounding pond	2	1	3	1	5	1
Rainfall	2	1	218	52	220	28
Availability of forage area						
With forage area	290	86	-	-	290	38
Without forage area	49	14	-	-	49	6
Forage Area (ha)	0.43	-	-	-	-	-
Type of forage grown*						
Napier	279	90	-	-	279	90
Guinea grass	7	2	-	-	7	2
Mulato	3	1	-	-	3	1
Sorghum	3	1	-	-	3	1
Paragrass	2	1	-	-	2	1
Others	16	5	-	-	16	5
Farm Location						
Lowland	-	-	182	41	182	41
Moderately hilly	-	-	137	31	137	31
Upland	-	-	124	28	124	28
Herd composition*						
Crossbreed	1,208	60	197	25	1405	50
Native	140	7	584	73	724	26
Riverine	675	33	22	3	697	25

* Multiple response

3.3. Herd Management Systems

Whether buffaloes are confined or allowed to graze significantly influences manure management practices. In confinement systems, manure accumulates in the animal housing, making it easier to collect and manage. By contrast, grazing systems often result in manure being left where it is deposited on pasture. Survey results indicated that the majority of farmers (69%) adopt a mixed approach, combining both grazing and confinement practices (Figure 3). The draft buffaloes are typically allowed to graze (while tethered) during the cooler parts of the day between 5:00 AM to 9:00 AM and again at 4:00 PM to 6:00 PM, after which they are then housed. A similar approach is observed with dairy buffaloes, particularly for calves and non-pregnant, non-lactating animals. Lactating and pregnant dairy buffaloes, on the other hand, are generally kept in confinement to allow better monitoring of their condition and to conserve their energy for milk production by minimizing their movement. Meanwhile, non-lactating and non-pregnant cows, heifers, bulls, and calves are allowed to graze during the cooler parts of the day.

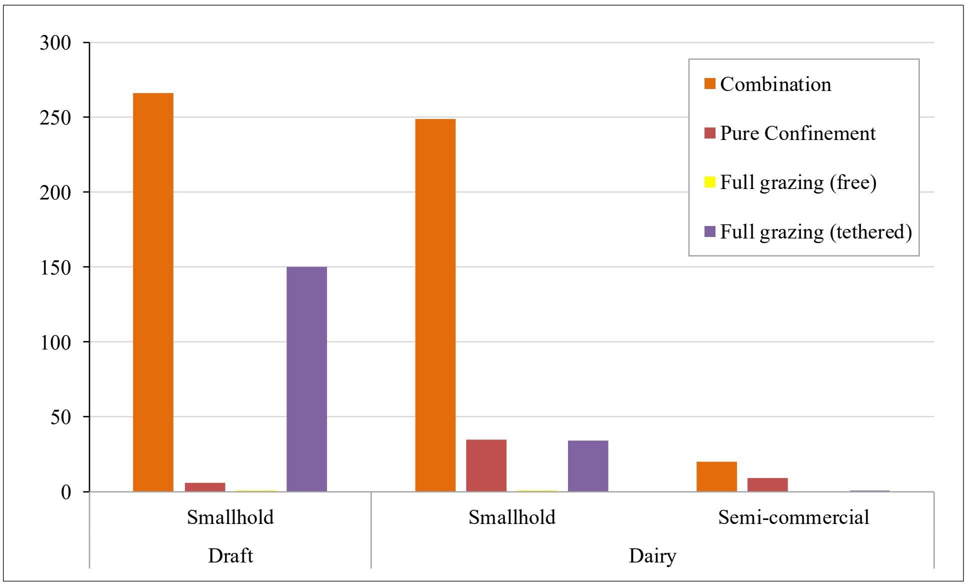


Figure 3. Herd management system of draft and dairy buffalo farmers according to farm classification, Philippines, 2024

In the pure confinement system, primarily practiced by dairy buffalo farmers, animals are housed throughout the year and are fed using a cut-and-carry method, in which fresh forage such as Napier grass, Star grass, Mulato or mixed native grasses, and other feed are harvested and brought to them. By contrast, the full grazing system allows buffaloes to graze (either tethered or free-range) in open areas with native grasses or in fields after crops have been harvested.

3.4. Manure Management Systems

Manure management contributes to GHG emissions through the release of methane (CH_4) and nitrous oxide (N_2O) (directly and indirectly) during decomposition. The amount of emissions produced is highly affected by the quantity of manure produced and the methods used to manage it. CH_4 emissions are influenced by the portion of the manure that decomposes anaerobically. By contrast, direct N_2O emissions result from the processes of nitrification and denitrification, which are influenced by the nitrogen and carbon content of the manure, as well as the duration of storage and the type of treatment applied [5]. In this study, only the emissions of methane from manure management were calculated.

Buffalo farmers often use multiple manure management systems, and manure is transferred from one system into another system, staying in each system for different durations. For farms that use a combination of grazing and confinement, some portion of the manure is deposited in the grazing area, while the manure excreted during the confinement period is piled near the shed (i.e., solid storage), dumped in the environment or composted. Generally, for farmers practicing pure confinement or a combination, manure is often stockpiled near the animal pen and allowed to decompose for some weeks. After that, usually during land preparation for crops, the semi-decomposed manure is incorporated into the cropland soil as an organic soil conditioner.

To properly account for the manure management systems (MMS) used, both the fraction of manure managed in each system and the duration it remains in each MMS were considered. For example, if the first MMS is solid storage and it retained in that MMS for 60 days, its share was calculated as a fraction of the year (i.e., 60/365). If, after solid storage, the manure is applied to crops, the remaining fraction of the year was allocated to the MMS "applied to crops". If a portion of the manure is reported to be managed under different MMS, then the corresponding percentage was allocated accordingly. This is to ensure correct estimation of the emission factor, which represents kg CH_4 per head per year.

Manure management practices on buffalo farms is influenced by herd size, herd management system and season, as shown in Table 4. The results show that in smallholder systems, the predominant manure management practice during the dry season (DS) is leaving manure in the grazing area, accounting for 56.51% of total manure. Notably, this fraction increases to 60.08% during the wet season (WS). This increase is attributed to the cooler temperatures in the WS, which allow buffaloes to graze for longer periods. On average, 58.30% of the manure managed by smallholder farms annually is left to decompose in grazing areas. This practice is common due to the open grazing and tethering systems traditionally employed by smallholder farmers, who often lack animal housing and structured waste management facilities. Less CH_4 is produced under this practice because the decomposition occurs under aerobic conditions. However, it may pose challenges such as nutrient runoff into nearby water bodies during the rainy season, contributing to environmental pollution [24] and direct and indirect N_2O emissions [25]. These nutrient losses were not measured or calculated in this study.

Leaving manure on pasture is also common in semi-commercial farms although less prevalent, accounting for 34.42% of manure during the DS, 30.49% in the WS, and a weighted average of 32.46%. This lower percentage is due to the difficulty of grazing more than ten buffaloes and the limited availability of grazing areas that can accommodate larger herds. Also, some semi-commercial farms, benefiting from higher income, had adopted improved practices such as proper animal housing and established forage areas to enable them to use a pure confinement system.

Table 4. Percent of manure managed in each manure management system on small hold and semi-commercial buffalo farms in the Philippines, 2024

MMS	Smallhold			Semi-commercial		
	DS	WS	Weighted Average	DS	WS	Weighted Average
Pasture/Range/Paddock	56.51	60.08	58.30	34.42	30.49	32.46
Daily spread	1.05	0.98	1.01	3.33	3.33	3.33
Liquid/slurry	0.43	0.36	0.39	0.97	1.67	1.32
Solid storage	5.69	6.92	6.31	10.89	12.41	11.65
Composted	1.82	1.65	1.74	3.22	3.27	3.24
Dried and burned	0.31	0.30	0.30	0.00	0.00	0.00
Applied to crops	32.59	28.32	30.45	46.20	48.82	47.51
Dumped in environment	1.60	1.39	1.49	0.97	0.00	0.49
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

NB: DS – Dry Season; WS – Wet Season.

The result of the survey further showed that 20.91% of buffalo farmers stock pile the manure near the animal shed. However, on average, the manure remains piled for an average of 53.05 days on smallhold farms and 115.50 days on semi-commercial farms. Hence, when calculated as a fraction of the year, solid storage is only 6.31% of average annual management on smallhold farms and 11.65% on semi-commercial farms. After some weeks in the solid storage system, most farmers apply the partially decomposed manure to their crop land, which accounts for a significant portion of annual average management in both smallholder farms (30.45%) and semi-commercial farms (47.51%). This practice is more common in semi-commercial farms than in smallholder farms, because more manure is generated in semi-commercial farms than in smallholder farms. Semi-commercial farms often operate with a dual focus on livestock and crop production. Hence, they utilize manure as a cost-effective organic fertilizer to enhance soil fertility and crop yields [26]. It is also notable that a higher percentage of farmers practice solid storage during the wet season compared to the dry season. According to the farmers, stockpiled manure becomes wet during the rainy season, making it difficult to haul. As a result, they tend to leave the manure in place until the dry season, when it is easier to transport and apply to their crop or forage areas.

Composting (with the use of worms or inoculants), which enhances nutrient recycling and reduces methane emissions [27], is practiced by only 1.74% of smallholder farms and 3.24% of semi-commercial farms. The main reason farmers do not practice this environment friendly MMS is the lack of a sustainable market for composted buffalo manure. This highlights the need for action from relevant agencies to establish a reliable market for composted manure, enabling it to be sold as a valuable organic fertilizer.

Only 1.49% of smallholder farms and 0.49% of semi-commercial farms flush a portion of the manure into a water body, crop field, or vacant area without treatment, generally termed as "dumped in the environment". The lower percentage of semi-commercial farms practicing this undesirable MMS may be attributed to greater awareness and access to resources [28]. Their larger scale also allows for economies of scale, making the adoption of improved systems more feasible and beneficial for nutrient recovery. By contrast, for smallholder farms, dumping manure in the environment remains a convenient and low-cost method of managing small volumes of waste. Nevertheless, dumping manure directly into the environment, such as into water bodies, fields, or vacant land without treatment can have significant environmental and public health impacts.

Some dairy buffalo farmers also practice scraping manure from the animal shed every morning before milking and spreading it onto nearby forage or crop areas, which are usually located adjacent to the buffalo shed. This practice is more common among semi-commercial farms (3.3%) than smallholder farms (1.01%), as many of the former operate pure confinement or a combination of confinement and grazing systems that result in manure accumulation in the animal shed.

A small number of buffalo farms manage manure in the form of liquid or slurry. Slurry is produced when urine and other liquid waste, such as water used for cleaning the shed, mixes with manure and the slurry is flushed into a waste pond. This method is used by 1.32% of semi-commercial farms and 0.39% of smallholder farms, which is as expected given that semi-commercial farms generate larger volumes of liquid waste.

Finally, the practice of burning dried manure for use as fuel or mosquito repellent is negligible but persists in smallholder systems, and was reported by 0.30% of farms. These findings highlight differences that reflect the distinct resource availability, farm management strategies, and environmental consideration inherent to each farm type, as well as the effects of seasonal climate on manure management practices.

The manure management systems (MMS) documented in this study differ significantly from the results reported in a study from Nepal et al. [17]. In that study, MMS differed between plains and hill regions, with dry lot (i.e., manure remains in the paved or unpaved confinement area), solid storage and burning for fuel dominating in the former, and dry lot and solid storage dominating manure management practices in the latter. Our results also differ from assumptions used in global modelling of manure management emissions for East and Southeast Asia [28]. That study assumed for dairy buffalo, 53.60% managed as liquid slurry, 31.10% burned for fuel, 13.30% spread daily, and 2.00% managed as solid storage; and for buffalo raised for meat production, 61.20% liquid slurry, 28.60% burned for fuel, 9.10% spread daily, and 0.80% solid storage. These values represent averages derived from literature sources, national inventory reports, and expert judgment, which likely contributes to the substantial disparity with the findings of this study. This discrepancy underscores the critical need for country-specific MMS data to improve the accuracy of GHG emission estimates from livestock.

3.5. Tier 1 vs. Tier 2 Manure Management Systems

The Philippine's national GHG inventory uses the 2006 IPCC Guidelines supplemented with expert judgement as the sources of information for the fraction of manure managed in each MMS by buffalo farmers. Table 5 compares the fraction of manure managed in each MMS assumed in the Tier 1 method and the results of this farm survey.

Table 5. Comparison of fractions of manure managed in different manure management systems according to the Tier 1 method and the survey results, Philippines, 2024

Manure Management System	Tier 1		Survey Result	
	Smallhold	Semi-commercial	Small hold	Semi-commercial
Liquid slurry without natural crust cover	0%	0%	0.39%	1.32%
Solid storage	0.0%	17.3%	6.31%	11.65%
Dry lot	32.5%	24.5%	0.00%	0%
Daily spread	0.0%	0.0%	1.01%	3.33%
Composting - (using worms or inoculants)	0.0%	0.0%	1.74%	3.24%
Burned for fuel or waste - sun dried dung burned for fuel	0.0%	0.0%	0.30%	0%
Biogas digester - low leakage: high quality gastight storage	0.0%	7.4%	0.00%	0%
Pasture/range/paddock	67.5%	50.9%	58.26%	32.46%
Applied to crops	0.0%	0.0%	30.46%	47.51%
Disposed in environment	0.0%	0.0%	1.53%	0.49%
Total Percentage	**100.00%**	**100.00%**	**100.00%**	**100.00%**

Table 5 clearly shows that using Tier 1, the manure management systems for smallholder farms were limited to pasture/range/paddock (67.5%) and dry lot (32.5%), while the use of biogas digesters and solid storage was included for semi-commercial farms. It can be noted that there is a significant discrepancy between the MMS distribution in Tier 1 and the results of the survey. In particular, the Tier 1 method assumes significant portions managed in dry lot, whereas farmers in the Philippines did not report leaving manure in the place where buffalo are kept. However, the farmers interviewed did report applying manure to cropland, which is not considered in the Tier 1 assumptions. These differences are likely to have significant effects on the estimated CH_4 and N_2O emissions from manure. This is because the fraction of manure allocated to each MMS serves as a multiplicand in the calculation of emission factors for both gases.

Conversely, the survey results provide a more comprehensive insight on the operations performed by the farmers in handling manure in the Philippines. The data revealed that both small hold and semi-commercial farms employ similar processes for their MMS. Deposit of dung and urine on pasture/range/paddock is prevalent on both farm types, but with some differences in the proportions of manure managed in this way (i.e., an average of 58.26% and 32.46% respectively). These figures are followed by the manure applied to crops, especially on semi-commercial farms (47.51%) but also on smallholder farms (30.46%). Solid storage also emerges as a slightly less common practice on both farm types, averaging 6.31% and 11.65% respectively. Solid storage is somewhat similar to dry lot systems, where manure is piled in an open area, but is intentionally piled and stored in place for extended periods, typically several months. Other practices used included daily spread, composting in static piles, and disposal in the environment, but these were less common.

3.6. Methane Emission Factor from Manure Management for Buffalo

Based on the results of the survey on manure management practices and detailed country-specific information on buffalo production systems, Philippines-specific emission factors (EF) for CH_4 emissions from manure management systems (MMS) were estimated. The estimation method followed the formulas provided in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories and was implemented using an Excel spreadsheet. The emission factor represents a standardized value expressed as kilograms of CH_4 per animal per year. It is multiplied by the buffalo population, categorized by production type, to calculate total CH_4 emissions from manure in the buffalo sector. The estimation of a Tier 2 CH_4 emission factor for manure involved calculating a weighted average methane conversion factor (MCF), based on the proportion of manure managed in each waste management system within regions with different climate conditions, using the MCF values for each manure management system given in the IPCC Guidelines owing to lack of country-specific measurements. The average MCF was then multiplied by the volatile solid (VS) excreted per head per day, the maximum methane-producing capacity of the manure (Bo) for each buffalo category, and 365 days (Equation 1).

$$EF_T=(VS_T\times 365)\times [B_{o,T}\times 0.67\ kg/m^3\ x \sum_{S,k}\frac{MCFS,k}{100}\times MS_{(T,S,k)}] \tag{1}$$

where, EF_T is emission factor for a specific animal sub-category, T, kg CH_4 head^{-1} year^{-1}; VS_T is daily volatile solids excreted by animal sub-category, T, kg dry matter head^{-1} year^{-1}; $B_{o,T}$ is the maximum methane producing capacity for manure produced by sub-category T, m^3 CH_4^{-1} kg VS excreted; 0.67 is the conversion factor of m^3 CH_4 to kg CH_4; $MCF_{S,k}$ is methane conversion factors for each manure management system, *S*, by climate region, *k*, %; $MS_{T,S,k}$ is fraction of manure from livestock sub-category T handled using manure management system *S* in climate region *k*, dimensionless.

The average Tier 2 CH_4 emission factor from buffalo manure, and its difference with the Tier 1 emission factor (EF) over a 28-year period (1994–2022), is presented in Table 6. Using the Tier 1 method, the default EF is 2 kg CH_4 head^{-1} year^{-1}, regardless of animal classification, farm type, or climatic condition (temperate or warm). According to the IPCC 2006 Guidelines, the uncertainty associated with the Tier 1 emission factor is typically around ±30%, with some cases reaching up to ±50%. As shown in the table, the Tier 2 results reveal that the EF for smallholder farms is 8–10% higher than the Tier 1 EF, but remaining within the expected range of uncertainty. However, for semi-commercial farms, the Tier 2 EF was 39–42% higher than the Tier 1 EF, already approaching or exceeding the upper bound of the Tier 1 uncertainty estimate. More notably, for commercial farms, the Tier 2 EF shows a significantly larger deviation (88–92% higher than the Tier 1 EF), which is well beyond the uncertainty range cited by the IPCC.

Table 6. Methane emission factor (kg CH_4 head⁻¹ year⁻¹) for buffalo manure management from 1994 to 2022 using the Tier 2 method, and percent difference compared to the Tier 1 emission factor

Year	Smallhold			Semi-commercial			Commercial			Overall		
	EF	Diff. from Tier 1	% Diff.	EF.	Diff. from Tier 1	% Diff.	EF	Diff. from Tier 1	% Diff.	EF	Diff. from Tier 1	% Diff.
1994	2.16	0.16	8.2	2.78	0.78	39.10	3.76	1.76	88.1	2.80	0.80	40.1
1995	2.16	0.16	8.2	2.78	0.78	39.10	3.76	1.76	88.1	2.80	0.80	40.1
1996	2.17	0.17	8.3	2.78	0.78	39.10	3.76	1.76	88.2	2.80	0.80	40.2
1997	2.17	0.17	8.3	2.78	0.78	39.20	3.76	1.76	88.2	2.80	0.80	40.2
1998	2.17	0.17	8.5	2.79	0.79	39.50	3.77	1.77	88.7	2.81	0.81	40.5
1999	2.17	0.17	8.4	2.79	0.79	39.40	3.77	1.77	88.5	2.81	0.81	40.4
2000	2.17	0.17	8.5	2.79	0.79	39.50	3.77	1.77	88.7	2.81	0.81	40.5
2001	2.17	0.17	8.6	2.79	0.79	39.70	3.78	1.78	88.9	2.81	0.81	40.7
2002	2.17	0.17	8.6	2.79	0.79	39.70	3.78	1.78	89	2.81	0.81	40.7
2003	2.18	0.18	8.8	2.80	0.80	40.10	3.79	1.79	89.5	2.82	0.82	41.1
2004	2.18	0.18	9	2.81	0.81	40.30	3.80	1.80	89.8	2.83	0.83	41.3
2005	2.18	0.18	9.2	2.81	0.81	40.70	3.81	1.81	90.5	2.83	0.83	41.7
2006	2.19	0.19	9.3	2.82	0.82	40.80	3.81	1.81	90.6	2.84	0.84	41.8
2007	2.19	0.19	9.3	2.82	0.82	40.90	3.81	1.81	90.7	2.84	0.84	41.8
2008	2.19	0.19	9.3	2.82	0.82	40.90	3.82	1.82	90.8	2.84	0.84	41.9
2009	2.19	0.19	9.4	2.82	0.82	41.00	3.82	1.82	90.8	2.84	0.84	41.9
2010	2.19	0.19	9.4	2.82	0.82	41.10	3.82	1.82	90.9	2.84	0.84	42.0
2011	2.19	0.19	9.4	2.82	0.82	41.10	3.82	1.82	91	2.84	0.84	42.0
2012	2.19	0.19	9.5	2.82	0.82	41.20	3.82	1.82	91.1	2.84	0.84	42.1
2013	2.19	0.19	9.5	2.82	0.82	41.20	3.82	1.82	91.2	2.84	0.84	42.2
2014	2.19	0.19	9.6	2.83	0.83	41.30	3.83	1.83	91.3	2.84	0.84	42.2
2015	2.19	0.19	9.6	2.83	0.83	41.40	3.83	1.83	91.4	2.85	0.85	42.3
2016	2.19	0.19	9.6	2.83	0.83	41.40	3.83	1.83	91.4	2.85	0.85	42.3
2017	2.19	0.19	9.7	2.83	0.83	41.50	3.83	1.83	91.5	2.85	0.85	42.4
2018	2.19	0.19	9.7	2.83	0.83	41.60	3.83	1.83	91.6	2.85	0.85	42.5
2019	2.19	0.19	9.7	2.83	0.83	41.60	3.83	1.83	91.7	2.85	0.85	42.5
2020	2.20	0.20	9.8	2.83	0.83	41.70	3.84	1.84	91.8	2.85	0.85	42.6
2021	2.20	0.20	9.8	2.83	0.83	41.70	3.84	1.84	91.9	2.85	0.85	42.6
2022	2.20	0.20	9.9	2.84	0.84	41.80	3.84	1.84	92	2.85	0.85	42.7

For smallholder and semi-commercial buffalo, although the calculated volatile solid (VS) excretion rates (i.e., 3.7 and 3.0 kg VS head⁻¹ day⁻¹, respectively) are lower than the IPCC Tier 1 assumption (i.e., 3.9 kg VS head⁻¹ day⁻¹), average MCF values (i.e., 2.6% and 4.3%) were higher than the IPCC Tier 1 assumption (i.e., 2%). For commercial buffalo farm, VS excretion and average MCF values (i.e., 4.2 kg VS head⁻¹ day⁻¹, 4.3%) were both higher than the IPCC Tier 1 assumptions. The main reason for higher VS excretion on commercial farms than the IPCC default assumption is the significantly lower feed digestibility (i.e., 52.5%) than assumed in the IPCC guidelines (i.e., 57.5%). This explains the significantly higher EF for commercial farm buffalo. One study from South Asia reported Tier 2 EFs from different agroecological zones that were lower than and greater than the Tier 1 default factors for that sub-continent, mainly due to differences in manure management systems [17]. Another study in South Asia also reported significant differences between country-specific manure management EFs for buffalo and the Tier 1 assumptions [29]. In that case, the estimated EF for adult non-dairy buffaloes was approximately 20% lower than the IPCC default value, while the EF for dairy buffaloes was similar to the Tier 1 value. However, that study did not clearly present the input data used in the calculations, so the reasons for their results could not be ascertained. Overall, these findings underscore the limitations of using Tier 1 default assumptions for national inventories and highlight the value of country-specific Tier 2 emission factors, particularly for more intensive production systems where default estimates may substantially under- or over-estimate actual emissions.

The sampling strategy used in this study was designed to produce representative data at national level, but not for each region. Therefore, EFs between regions were not compared. Nevertheless, three main regional factors are likely to affect average national EFs: (1) the distribution between regions of populations of draft and dairy buffalo in different farm types, which would affect the calculation of weighted average national EFs for each farm type; (2) regional differences in diet composition and feed quality, which would affect volatile solid excretion (i.e., the parameter VS in Equation 1); and (3) regional differences in annual average temperature, which would affect the methane conversion factor (i.e., $MCF_{S,k}$ in Equation 1) and the calculation of weighted average national EFs. This study is a foundational study providing the first estimates at national level of manure management methane emissions using the Tier 2 method. Better quantification of factors affecting EFs in the main buffalo raising regions and regional differences would be a priority for future research.

4. Conclusions and Recommendations

This study addressed critical data gaps in manure management systems relevant to the national GHG inventory, particularly for methane (CH_4) emissions from buffalo in the Philippines. It documented the socio-economic and farm profiles of buffalo farmers, alongside the specific manure management practices applied, which is an essential input into development of a country-specific Tier 2 CH_4 emission factor (EF). Findings highlighted notable differences between dairy and draft buffalo farmer socio-economic and farm profiles. Respondents were predominantly married men, with an average household size of five and limited educational backgrounds. Dairy farmers had a stronger presence in cooperatives, while draft farmers were mostly unaffiliated with agricultural organizations. Additionally, farm type classifications revealed that draft buffalo farmers generally operated smallholder farms with fewer than five heads, whereas semi-commercial and commercial classifications were exclusive to dairy buffalo operations. Farm management practices also differed, with confined animal housing and forage production being more common in dairy farms, while grazing-based systems were prevalent among draft buffalo producers.

The dominant manure management system among smallholder farms was leaving manure in the grazing area (58.30%), followed by application to crops (30.45%) and solid storage (6.31%). In contrast, semi-commercial farms used more diverse management practices, with greater emphasis on crop application, solid storage, and composting. Notably, the default assumptions given in the 2006 IPCC Guidelines failed to capture the full spectrum of manure management practices observed in the field, such as application to crops and dumping in the environment, which contributes to under- or over-estimation of emissions when using the Tier 1 method. The calculated Tier 2 EF was 8-10% higher than Tier 1 for smallholder systems, but 39–42% and 88–92% higher for semi-commercial and commercial farms, respectively, exceeding the uncertainty margins estimated in the IPCC Guidelines. This highlights the importance of developing country-specific emission factors, particularly for unique and/or intensive production systems where Tier 1 default values may be insufficient.

The research provides empirical data to support more accurate manure CH_4 emission estimates from the buffalo sector in the Philippines. It enables the creation of Tier 2 country-specific emission factors suitable for use in the national GHG inventory and for archiving in the Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database. The data presented here on current manure management practices further provide insights into the potential for changing manure management systems to reduce GHG emissions and support sustainable resource use. This can inform future updating of the Philippines' Nationally Determined Contribution (NDC) to include practical measures and realistic targets for manure management as part of climate-smart agricultural planning.

Based on the findings, the following recommendations are proposed:

1. Institutionalize the use of Tier 2 methodologies in national GHG inventories for the livestock sector as well as in other sectors. This will improve the accuracy of GHG emission estimates and ensure policy decisions are based on localized data rather than generalized assumptions. A more precise inventory will support evidence-based policy-making and help the Philippines set realistic and effective emissions reduction targets, aligned with its commitments under the Paris Agreement.
2. Develop different CH_4 mitigation strategies tailored to the socio-economic conditions and farm types of dairy and draft buffalo producers. Support should consider variations in scale, manure handling practices, and access to technical or cooperative networks.
3. Promote improved manure management practices among smallholders, such as composting or application to crops, through training, subsidies, and extension services. These practices can both reduce emissions and improve soil fertility.

5. Declarations

5.1. Author Contributions

Conceptualization, E.V., A.W., and C.L.C.; methodology, E.V., A.W., and C.L.C.; software, A.W. and C.L.C.; data gathering, E.V., C.L.C., F.B., A.D., J.N., J.P.; J.T.N., C.C., and P.L.; formal analysis, E.V., C.L.C., J.N., and J.P.; resources, A.W., data curation, D.A.; writing—original draft preparation, E.V., A.W., and C.L.C.; writing—review and editing, E.V., A.W., and D.A.; visualization, E.V. and C.L.C.; supervision, E.V. and A.W.; project administration, E.V. and A.W.; funding acquisition, E.V. and A.W. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available as compliance to the Data Privacy Act 2012 of the Philippines.

5.3. Funding

This research has been funded by the New Zealand Climate Smart Agriculture Initiative to support the objectives of the Global Research Alliance on Agricultural Greenhouse Gases.

5.4. Acknowledgments

The authors gratefully acknowledge the New Zealand Government for its technical and financial support, which enabled the initiation and successful completion of this research. We also extend our sincere gratitude to the Philippine Carabao Center for their invaluable technical and administrative assistance, which was instrumental in the operationalization of this study. This work was made possible through the strong partnership and shared commitment of both organizations to advancing improved national greenhouse gas inventory in the Philippines.

5.5. Institutional Review Board Statement

Not applicable.

5.6. Informed Consent Statement

Informed consent was obtained from all participants involved in the study. Participants were fully informed about the objectives of the research, the procedures involved, and the potential risks and benefits. They were also assured that their participation was voluntary, and were informed that they could withdraw at any point given in time without any consequences. The confidentiality of participants' data was maintained throughout the study.

5.7. Declaration of Competing Interest

The authors declare that there are no conflicts of interest concerning the publication of this manuscript. Furthermore, all ethical considerations, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

6. References

[1] United Nations Framework Convention on Climate Change. (2024). Key aspects of the Paris Agreement. UNFCCC. Available online: https://unfccc.int/most-requested/key-aspects-of-the-paris-agreement (accessed on November 2025).

[2] Denchak, M., & Hu, S. (2025). Paris climate agreement: Everything you need to know. Natural Resources Defense Council. Available online: https://www.nrdc.org/stories/paris-climate-agreement-everything-you-need-know (accessed on November 2025).

[3] Qiu, J., Seah, S., & Martinus, M. (2024). Examining climate ambition enhancement in ASEAN countries' nationally determined contributions. Environmental Development, 49, 100945. doi:10.1016/j.envdev.2023.100945.

[4] UNFCCC. (2018). Decision 18/CMA. 1, Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, FCCC/PA/CMA/2018/3/Add. 2. Bonn: United Nations Framework Convention on Climate Change. Available online: https://unfccc.int/documents/193408 (accessed on November 2025).

[5] Intergovernmental Panel on Climate Change (IPCC). (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (Eds). Published by IGES, Japan.

[6] Global Research Alliance. (2018). Livestock Development and Climate Change: The benefits of advance greenhouse gas inventories. Available online: https://globalresearchalliance.org/wp-content/uploads/2018/06/Inventory-Brochure-on-Livestock-Development-and-Climate-Change-2016.pdf (accessed on November 2025).

[7] Wilkes, A. & van Dijk, S. (2018). Tier 2 Approaches in the Livestock Sector: A Collection of Greenhouse Gas Inventory Practices. Available online: https://globalresearchalliance.org/wp-content/uploads/2018/12/Livestock-Tier-2-collection_Final_181130.pdf (accessed on November 2025).

[8] Republic of the Philippines. (2021). Nationally Determined Contribution Communicated to the UNFCCC on 15 April 2021. Available online: https://unfccc.int/sites/default/files/NDC/2022-06/Philippines%20-%20NDC.pdf (accessed on November 2025).

[9] Philippine Climate Change Commission. (2025). Philippines' First Biennial Transparency Report. Manila. Available online: https://unfccc.int/documents/646250 (accessed on November 2025).

[10] Valiente, E. P., Sobremisana, M. J., Vergara, D. G. K., & Dizon, J. T. (2023). Waste management practices of dairy buffalo farmers in Nueva Ecija, Philippines. Journal of Environmental Science and Management, 26(2), 17-30.

[11] Delos Santos, D. T., Torres, M. M., & Peria, J. N. T. (2025). Quantifying Greenhouse Gas Emissions of Water Buffalo by Age Category in Central Aurora, Philippines. International Journal of Multidisciplinary: Applied Business and Education Research, 6(6), 2755–2765. doi:10.11594/ijmaber.06.06.08.

[12] Gupta, P. K., Jha, A. K., Koul, S., Sharma, P., Pradhan, V., Gupta, V., Sharma, C., & Singh, N. (2007). Methane and nitrous oxide emission from bovine manure management practices in India. Environmental Pollution, 146(1), 219–224. doi:10.1016/j.envpol.2006.04.039.

[13] Nampoothiri, V. M., Mohini, M., Malla, B. A., Mondal, G., & Pandita, S. (2020). Animal performance, and enteric methane, manure methane and nitrous oxide emissions from Murrah buffalo calves fed diets with different forage-to-concentrate ratios. Animal Production Science, 60(6), 780–789. doi:10.1071/AN17727.

[14] Hidayat, C., Widiawati, Y., Tiesnamurti, B., Pramono, A., Krisnan, R., & Shiddieqy, M. I. (2021). Comparison of methane production from cattle, buffalo, goat, rabbit, chicken, and duck manure. IOP Conference Series: Earth and Environmental Science, 648(1), 12112. doi:10.1088/1755-1315/648/1/012112.

[15] Hassouna, M., van der Weerden, T. J., Beltran, I., Amon, B., Alfaro, M. A., Anestis, V., Cinar, G., Dragoni, F., Hutchings, N. J., Leytem, A., Maeda, K., Maragou, A., Misselbrook, T., Noble, A., Rychła, A., Salazar, F., & Simon, P. (2023). DATAMAN: A global database of methane, nitrous oxide, and ammonia emission factors for livestock housing and outdoor storage of manure. Journal of Environmental Quality, 52(1), 207–223. doi:10.1002/jeq2.20430.

[16] Beltran, I., van der Weerden, T. J., Alfaro, M. A., Amon, B., de Klein, C. A. M., Grace, P., Hafner, S., Hassouna, M., Hutchings, N., Krol, D. J., Leytem, A. B., Noble, A., Salazar, F., Thorman, R. E., & Velthof, G. L. (2021). DATAMAN: A global database of nitrous oxide and ammonia emission factors for excreta deposited by livestock and land-applied manure. Journal of Environmental Quality, 50(2), 513–527. doi:10.1002/jeq2.20186.

[17] Nepal, S., Byanju, R. M., Chaudhary, P., Rijal, K., Baskota, P., & Thakuri, S. (2023). Methane release from enteric fermentation and manure management of domestic water buffalo in Nepal. Environmental Monitoring and Assessment, 195(5), 603. doi:10.1007/s10661-023-11209-6.

[18] Teenstra, E. D., Vellinga, T. V., Aektasaeng, N., Amatayakul, W., Ndambi, OA., Pelster, D., Germer, Andreas, L., Opio, C., & Andeweg, K. (2014). Global assessment of manure management policies and practices (No. 844). Wageningen, The Netherlands: Wageningen UR Livestock Research. doi:10.6084/m9.figshare.8251232.

[19] Philippine Statistics Authority. (2022). Approving and adopting the revision in the classification of livestock and poultry farms from backyard and commercial to smallhold, semi-commercial and commercial farms, and the definitions by animal type. PSA Board Resolution No. 04 (2022). Manila: Philippine Statistics Authority Board. Available online: https://psa.gov.ph/system/files/psa-board/PSA%2520Board%2520Reso%2520No.%252004%2520series%2520of%25202022_0.pdf (accessed on November 2025).

[20] Johnson, D., Almaraz, M., Rudnick, J., Parker, L. E., Ostoja, S. M., & Khalsa, S. D. S. (2023). Farmer Adoption of Climate-Smart Practices Is Driven by Farm Characteristics, Information Sources, and Practice Benefits and Challenges. Sustainability (Switzerland), 15(10), 8083. doi:10.3390/su15108083.

[21] Aquino, D. L., Palacpac, E. P., Molina, A. M., Lacanilao, C. C., Garcia, N. P., Del Barrio, A. N., & Fujihara, T. (2024). Enhancing Growth and Milk Production of Dairy Buffaloes Through Home-Grown Forages and Complete Nutrient Diet. Online Journal of Animal and Feed Research, 14(2), 95–106. doi:10.51227/ojafr.2024.12.

[22] Wang, J., He, Y., Pang, K., Zeng, Q., Zhang, X., Ren, F., & Guo, H. (2019). Changes in milk yield and composition of colostrum and regular milk from four buffalo breeds in China during lactation. Journal of the Science of Food and Agriculture, 99(13), 5799–5807. doi:10.1002/jsfa.9849.

[23] Mloszewski, M. J., & Mahaney, W. C. (2021). A check-list of wild African Bovidae related to montane habitats, with an expanded note on geophagic behaviour of buffalo on Mount Kenya. Quaternary and Environmental Research on East African Mountains, 309–324. doi:10.1201/9781003211457-20.

[24] Keena, M. (2022). Eutrophication (algal blooms) in Big A fish kill in North Environmental Implications of Excess Fertilizer and Manure on Water Quality. Available online: https://www.ndsu.edu/agriculture/sites/default/files/2022-08/nm1281_0.pdf (accessed on November 2025).

[25] Cai, Y., & Akiyama, H. (2016). Nitrogen loss factors of nitrogen trace gas emissions and leaching from excreta patches in grassland ecosystems: A summary of available data. Science of the Total Environment, 572, 185–195. doi:10.1016/j.scitotenv.2016.07.222.

[26] Zhao, N., Ma, J., Wu, L., Li, X., Xu, H., Zhang, J., Wang, X., Wang, Y., Bai, L., & Wang, Z. (2024). Effect of Organic Manure on Crop Yield, Soil Properties, and Economic Benefit in Wheat-Maize-Sunflower Rotation System, Hetao Irrigation District. Plants, 13(16), 2250. doi:10.3390/plants13162250.

[27] Manea, E. E., Bumbac, C., Dinu, L. R., Bumbac, M., & Nicolescu, C. M. (2024). Composting as a Sustainable Solution for Organic Solid Waste Management: Current Practices and Potential Improvements. Sustainability (Switzerland), 16(15), 6329. doi:10.3390/su16156329.

[28] Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B., & Steinfeld, H. (2013). Greenhouse gas emissions from ruminant supply chains—A global life cycle assessment. Rome: Food and Agriculture Organization (FAO). Available online: http://www.fao.org/3/i3461e/i3461e.pdf (accessed on November 2025).

[29] Samal, A., Sahu, S. K., Mishra, A., Mangaraj, P., Pani, S. K., & Beig, G. (2024). Assessment and Quantification of Methane Emission from Indian Livestock and Manure Management. Aerosol and Air Quality Research, 24(6), 230204. doi:10.4209/aaqr.230204.