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Enteric Methane Emission Factor for Dairy Farming in Peru

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Abstract: The objective of this study was to determine the enteric methane (CH_4) emission factor (EF) at the national level for Peruvian dairy cattle following the IPCC Tier II (2006, 2019) methodology. Data were collected from seven regions of Peru and classified according to the type of feeding as intensive, semi-intensive or extensive. It included farm information (geolocation) and livestock information for two seasons of the year. At the national level, lactating cows obtained the highest EF with 117 kg CH_4/head/year, followed by heifers from 15 to 24 months of age (91 kg), non-lactating cows (74 kg), heifers from 12 to 15 months of age (67 kg), calves (62 kg) and pre-weaned calves (16 kg). Additionally, the highest EF was reported for lactating cows in the intensive system (151.8 kg CH_4/head), which is 46.8 kg CH_4/head more per year than that reported in the semi-intensive and extensive systems in the same animal category. The combined uncertainty in all animal categories was low to very low (between 9.4 and 18.72%), except for that of lactating cows, which was low to medium (22.24 and 26.72%). These results allowed us to find the EF that exerts the most pressure according to the level of intensity in Peruvian dairy farming.

Keywords: greenhouse gas; livestock systems; milk production; Tier II-IPCC

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1. Introduction

In the last nine years, milk production in Peru has increased by 7.98%, which corresponds to 165.2 t more than that reported for the year 2015 (1903 t. [1]). With these figures, fresh milk production accounts for 12.6% of the gross domestic value of the Peruvian livestock subsector [2]. The above trend is the result of recent government interventions to improve the competitiveness of dairy farming, where genetic improvement of animals, the use of new feed resources, the implementation of adequate tools for prevention and sanitary control and the development of productive infrastructure, among others, have been promoted [3].

The intensification of dairy production at the farm level is associated with greenhouse gas (GHG) emissions; authors such as Ribeiro-Filho et al. [4] and Gerber et al. [5] state that as livestock productivity increases, GHG emissions per kilogram of milk produced are reduced, but there are other authors who highlight the benefits of traditional livestock systems because they are less dependent on the use of external inputs [6]. The above principles served as the scientific basis for the Peruvian government to establish its environmental commitments in supreme decree N003-2022-MINAM [7], where they approved the objectives agreed in the Kyoto Protocol and the Paris Agreement developed by the United Nations Framework Convention on Climate Change to implement actions to mitigate, among other GHG-emitting sources, the 15,432.44 GgCO_{2eq} coming from the enteric fermentation process carried out by ruminants [1]. Nevertheless, the measurement of GHG emissions in the Latin American and Caribbean region remains lower compared to that in developed countries in North America, Europe and Oceania [8].

The starting point for meeting the goal of reducing GHG emissions at the farm level is to accurately quantify methane (CH_4) gas production by animal groups and animal management [9,10]. Based on these needs, the Intergovernmental Panel on Climate Change (IPCC) has developed guidelines for quantifying anthropogenic GHGs [11]. According to Niu et al. [12], the IPCC created three levels of calculation, or TIERs, where higher levels improve inventory accuracy and reduce uncertainty but increase complexity and the requirement of economic resources and specialized equipment for quantification. For example, the TIER-I methodology uses international values for the emission factor (EF) obtained by the IPCC, and these emissions are on a global or continental scale; TIER II incorporates country-specific information (such as milk production, animal live weight, nutritional quality of feed, among others) into the IPCC equations to estimate the EF; and TIER III uses country-specific equations and data obtained from constant monitoring.

The GHG balance is different according to the degree of intensification of the dairy system, which is indirectly associated with the type of feed [13,14]; this is why the objective of the present work was to determine the emission factor of enteric methane in three dairy production systems with different degrees of intensification, from the information collected and systematized from both rainy and dry seasons for Peru.

2. Materials and Methods

2.1. Selection of Regions and Characterization of Livestock Systems

Seven Peruvian provinces with three different ecozones (high Andean, tropical and coastal) were selected for this study because of their impact on milk productivity. According to statistical data for the year 2021, the regions of Cajamarca, Arequipa, Puno, Lima and La Libertad were home to 50.6% of the total number of lactating cows at the national level (n = 934,422) and produced 64.3% of the total milk (2,180,708 t) in the Peruvian territory [2]. In addition to the above regions, San Martin and Ucayali were also included, which represent the semi-intensive and extensive dairy systems of the Peruvian tropics. The evaluations were carried out in fifty-two farms selected in the seven regions during the dry and rainy seasons. This is due to the changes in temperature and rainfall that Peru experiences during the year due to its location in the tropical region of the southern hemisphere of the planet.

Dairy cattle production systems in Peru were characterized for this work, based on the opinions of experts, following the procedure proposed by the IPCC [15], who defined the type of feeding as the differentiating variable among the production systems to be evaluated. Thus, the production systems were classified as intensive, semi-intensive and extensive based on the amount consumed daily per animal of some agro-industrial input or grains of several inputs [16]. For example, in the intensive system, the average consumption per animal of grain or agro-industrial input is equal to or greater than 5 kg per day plus pasture or forage; for the semi-intensive system, the average consumption per animal of grain or agro-industrial input is less than 5 kg per day plus pasture or forage; and for the extensive system, only pasture or forage is consumed.

2.2. Collection of Data and Feed and Milk Samples

The data collected for each of the two seasons of the year included basic farm information (geolocation) as well as livestock data. The livestock data collected began with the inventory according to the following categories: lactating cows (females older or equal to 2 years of age that were in production and milked regularly), non-lactating cows (cows that were not in production stage), heifers (females 15 to 24 months of age that had a confirmed pregnancy diagnosis), heifers (females 12 to 15 months of age that were between the juvenile stage and sexual maturity), calves (young growing cattle in the development stage after weaning until 12 months of age) and pre-weaned calves (animals from birth to weaning).

On each farm, a minimum population of 20 animals per category was selected for weighing. Weighing was carried out twice per season for each animal using a tape measure. In addition, the daily milk production per animal was recorded and sampled as described by Thomassen and de Boer [17]; this procedure was carried out twice per animal per season. The milk samples collected were sent to the Milk and Meat Technology Laboratory of the Universidad Nacional Agraria La Molina for infrared analysis of their fat content using the MILKOSCAN FT1® model (IndiFOSS Analytical Pvt. Ltd., Gujarat, India).

In addition, the amount of supplement and forage supplied was quantified, and representative samples of all feeds were obtained for chemical nutritional analysis. Feed samples for both seasons of the year were sent for analysis to the Feed Nutritional Evaluation Laboratory of the Universidad Nacional Agraria La Molina. The moisture content of the food was analyzed according to the method of the Association of Official Analytical Chemists [18]. Likewise, the neutral detergent fiber content was found using the ANKOM® equipment (Ankom Technology Corporation, Fairport, NY, USA) according to the methodology described by Van Soest [19], and the in vitro digestibility of dry matter was determined with the ANKOM DaisyII Incubat® [20].

2.3. Estimation of the Enteric Methane Emission Factor

The estimation of the enteric methane (CH_4) emission factor started with the calculations to determine the net energy (*NE*) required by animal for maintenance (*NEm*) requirements, which was performed according to equation 10.3 and the data reported in table 10.4 of the IPCC guide [11]. This equation establishes that the live weight data for each animal category should be multiplied with a coefficient (*Cfi*) that can be used for lactating cattle (0.386 MJ/day/kg) or for non-lactating cattle (0.322 MJ/day/kg).

$$NEm = Cfi \times (Weight)^{0.75}$$

As for the *NE* for animal activity (*NEa*), this was found from the values of *NEm* and the activity coefficient (*Ca*) [11]. This coefficient is a function of the dairy production system; for example, it was set to zero for the intensive system, 0.17 for the semi-intensive system and 0.36 MJ/day/kg for the extensive system [11].

$$NEa = Ca \times NEm$$

Likewise, *NE* needed for growth (*NEg*) was calculated with data obtained in the field as live weight (*BW*, kg), adult body weight (*MW*, kg) and daily weight gain (*WG*, kg/d) for each category plus the coefficient (*C*) defined by the NRC [21] for female cows (0.8), castrated cattle (1.0) or bulls (1.2).

$$NEg = 22.02 \times \left(\frac{BW}{C \times MW}\right)^{0.75} \times WG^{1.097}$$

On the other hand, *NE* for lactation (*NEl*) was found with equation 10.8 [11], where it incorporated the amount of milk produced (*MY*) and milk fat content (*Fat*).

$$NEl = MY \times (1.47 + 0.40 \times Fat)$$

The *NE* required for pregnancy (*NEp*) was calculated from the multiplication of the found value of *NEm* and the pregnancy coefficient (*Cp*) established for cattle, which was 0.1, taken from Table 10.7 [11].

$$NEp = Cp \times NEm$$

Additionally, the percentage of animals that were in this physiological state was determined for the different milk production systems; for example, it was considered that 70, 57 and 44% of the total number of lactating cows were pregnant in the intensive, semi-intensive and extensive systems, respectively. These data were obtained from the calving interval for the three systems [22–24]. For all animals that were in the dry cow and heifer category, *NEp* was estimated.

The neutral detergent fiber (*NDF*) of the ration was determined from the dry matter intake and the *NDF* content of all feeds, and the digestibility (*DE*) of the ration was determined by the multiplication between dry matter intake and the *in vitro* digestibility of dry matter percentage for concentrate and forage found for each feed. Subsequently, the relationship between available *NEm* and digestible energy (*REM*) was determined from equation 10.14 of the IPCC Guidelines [11].

$$REM = \left\lfloor 1.123 - \left(4.092 \times 10^{-3} \times DE\right) + \left(1.126 \times 10^{-5} \times DE^2\right) - \left(\frac{24.4}{DE}\right) \right\rfloor$$

In the same way, the relationship between the available NE in a diet for growth and the digestible energy consumed (REG) was determined with equation 10.15 [11].

$$REG = \left\lfloor 1.164 - \left(5.16 \times 10^{-3} \times DE\right) + \left(1.308 \times 10^{-5} \times DE^2\right) - \left(\frac{37.4}{DE}\right) \right\rfloor$$

With the values obtained for the different energy sources (NEm, NEa, NEl, NEp, NEg and DE (digestible energy)) and the two calculated ratios (REM and REG), the gross energy (GE) was found from equation 10.16 [11]. It is important to clarify that in no category evaluated was net energy for work considered, since dairy cattle are not employed for traction or loading activities.

$$GE = \frac{\left(\frac{NEm + NEa + NEl + NEp}{REM}\right) + \left(\frac{NEg}{REG}\right)}{DE}$$

The CH_4 conversion factor (Ym) was taken from Table 10.12 of the IPCC Guidelines [11]. For the case of lactating dairy cows, the DE and NDF values of the ration were considered within the decision criteria to establish the corresponding Ym, while for the rest of the cattle categories, only the DE values were taken into account. Finally, with the GE and Ym values, the enteric fermentation methane emission factor (EF) was determined for each category (equation 10.21) [11].

$$EF = \frac{\left[GE \times \frac{Ym}{100} \times 365\right]}{55.65}$$

The enteric methane EFs found were multiplied by the percentage of dairy cattle population in each production system to be reported as national values. The proportion per animal per system at the national level was estimated at 26% for the intensive system, followed by 36% for the semi-intensive and 38% for the extensive system. This proportion was found from the sum of the number of cows in the selected regions with respect to the total number of milking cows in these seven regions (*n* = 261,505); for example, in the seven regions, 67,590 cows were classified in the intensive system, 94,464 in the semi-intensive system and 99,451 cows in the extensive system. By expert judgment for each region and based on the definition of the use of agro-industrial by-products and grains in animal feed, the provinces of each region were classified in one of the systems.

2.4. Estimation Determination of the Uncertainty of the Enteric Methane Emission Factor

After calculating the EF for dairy cattle, the two sources of uncertainty according to the IPCC [11,15] were established; the first uncertainty was generated by the data resulting from the application of models or equations used in the calculation of the EF (uncertainty of the emission factor), and the second uncertainty originates from the data obtained during the visits to the farms (uncertainty of the activity data or parameters), which included information on milk production, milk fat percentage, in vitro digestibility of dietary dry matter, dietary neutral detergent fiber, weight and weight gain.

The uncertainty of the EF was calculated from the confidence interval and the mean of the enteric methane emission factors (kg/head/day) found for each animal category at each time of the year [11]. The uncertainty of activity data or parameters was worked based on expert judgment, following the procedure proposed by the IPCC [15]. Estimation by expert judgment was selected because the values obtained in some parameters evaluated in the field presented high deviations (>20%). The surveys were completed by a group of experts from governmental and private entities in the livestock sector in the regions evaluated in the study. Each upper and lower limit obtained from the survey for each of the evaluated parameters was averaged and then entered into equation 3.1 to find the uncertainty of the activity data or parameters [11].

The combination of the uncertainties generated by the EF and by the activity or parameter data was determined with method 1, also called error propagation (Equation 3.2A) [11]. The results obtained in the previous step were interpreted quantitatively as described in the protocol on uncertainty assessment in GHG inventories. For example, values less than 12.5% uncertainty are considered to have "very low" uncertainty, values between 12.6 and 22.5% are of "low" uncertainty, values from 22.6 to 30% have a "medium" uncertainty and values greater than 30% have "high" uncertainty [25].

3. Results

3.1. Characterization of the Systems

The average values and their standard deviations of productive parameters and diet digestibility for all categories of dairy cattle are presented in Table 1. The average live weight achieved by adult cows in intensive systems was higher than the weight of adult cows in extensive systems (706 and 497 kg, respectively). Lactating cows are between 32 and 60 kg below the values reported for adult weight, while the live weight of non-lactating cows was on average 9 kg less than the maximum or adult weight. The average live weights of heifers in the extensive and semi-intensive systems for both times of the year were lower than those reported for the same category in the intensive system. This same trend is repeated for the calves (after weaning until 12 months of age) and pre-weaned calves in the birth weight and live weight at birth categories.

Live weight gains in all categories were 62% higher in the intensive system compared to the semi-intensive and extensive systems. Likewise, it was observed that in the rainy season, weight gain was equal or higher than in the dry season, except for heifers from 12 to 15 months of age in the intensive system. As for the digestibility of the total diet, it was observed that this parameter ranges between 58 and 76%, where the minimum value was reported for the extensive system in most categories, while the maximum value was obtained for the calf diet prior to weaning. The NDF content of the diet is higher for the extensive system, followed by the semi-intensive and intensive systems (54, 52 and 39%, respectively).

Table 1. Productive parameters and digestibility of the diet of lactating cows and the rest of the categories by production system and season.

Item	Data Input to the Equations						Average (±Standard Deviation, %) by Production System		
	Rainy Season			Dry Season					
	Intensive System	Semi-Intensive System	Extensive System	Intensive System	Semi-Intensive System	Extensive System	Intensive System	Semi-Intensive System	Extensive System
Average live weight (kg)									
Adult animal	711	578	496	701	560	498	706 (±5.5)	569 (±2.9)	497 (±4.3)
Lactating cows	647	541	469	645	520	462	646 (±7.5)	530 (±9.6)	465 (±9.3)
Non-lactating cows	698	549	491	689	571	489	694 (±6.4)	560 (±9.3)	490 (±8.0)
Heifers (Females 15 to 24 months of age)	486	387	406	470	404	383	478 (±6.5)	396 (±7.96)	395 (±6.9)
Heifers (Females 12 to 15 months of age)	346	274	276	358	272	264	352 (±6.3)	273 (±8.4)	270 (±8.1)
Calves (after weaning until 12 months of age)	203	157	151	208	152	137	205 (±7.8)	155 (±8.4)	144 (±9.9)
Pre-weaned calves	75	70	67	79	72	64	77 (±7.3)	71 (±6.7)	65 (±11.9)
Birth weight	46	38	37	47	38	35	47 (±5.4)	38 (±6.2)	36 (±10.9)
Live weight gain (kg/day)									
Heifers (females 15 to 24 months of age)	0.83	0.47	0.41	0.83	0.45	0.39	0.83 (±6.7)	0.46 (±11.4)	0.40 (±11.8)
Heifers (females 12 to 15 months of age)	0.76	0.45	0.46	0.78	0.45	0.43	0.77 (±6.2)	0.45 (±8.7)	0.45 (±10.5)
Calves (after weaning until 12 months of age)	0.73	0.51	0.43	0.69	0.49	0.43	0.71 (±6.7)	0.50 (±9.5)	0.43 (±12.4)
Pre-weaned calves	0.48	0.39	0.34	0.54	0.38	0.34	0.51 (±9.4)	0.38 (±8.8)	0.34 (±10.8)
Other parameters evaluated									
Milk production (kg/cow milking/day)	29	10	7	29	8	6	28.7 (±18)	8.9 (±12.9)	6.7 (±11.9)
Milk fat percentage by sector (%)	3.5	4.0	3.9	3.6	3.5	3.4	3.5 (±6.6)	3.8 (±7.0)	3.6 (±6.9)
Pregnancy percentage (%)	70	57	44	70	57	44	70 (±11.6)	57 (±8.7)	44 (±10.1)
Average neutral detergent fiber of the diet (%)	40	53	59	38	52	55	39 (±8.6)	52 (±7.5)	57 (±10.3)

Table 1. *Cont.*

Item	Data Input to the Equations						Average (±Standard Deviation, %) by Production System		
	Rainy Season			Dry Season					
	Intensive System	Semi-Intensive System	Extensive System	Intensive System	Semi-Intensive System	Extensive System	Intensive System	Semi-Intensive System	Extensive System
Average digestibility of the diet (%)									
Lactating cows	70	64	62	69	61	59	69 (±7.3)	62 (±6.5)	60 (±9.8)
Non-lactating cows	62.8	59.2	59.7	61.0	61.2	57.1	62 (±6.8)	60 (±8.7)	58 (±10.5)
Heifers (females 15 to 24 months of age)	62.8	59.2	59.7	61.0	61.2	57.1	62 (±5.7)	60 (±7.8)	58 (±8.5)
Heifers (females 12 to 15 months of age)	62.8	59.2	59.7	61.0	61.2	57.1	62 (±5.7)	60 (±7.8)	58 (±8.5)
Calves (after weaning until 12 months of age)	62.8	59.2	59.7	61.0	61.2	57.1	62 (±5.7)	60 (±7.8)	58 (±8.5)
Pre-weaned calves	73.6	61.8	57.0	78.7	63.1	59.5	76 (±5.2)	62 (±6.4)	58 (±6.4)

In the intensive system, daily milk production was 28.7 kg/cow, which is 69% more than cows in the semi-intensive system and 77% more than cows in the extensive system. Regarding the percentage of fat in milk, cows in the semi-intensive system contributed the highest fat content, followed by cows in the extensive system and, finally, cows in the intensive system (3.8, 3.6 and 3.5%, respectively). Seventy percent of the cows in the intensive system were pregnant, while the semi-intensive and extensive systems had 13 and 26% fewer cows in pregnancy, respectively.

3.2. Energy Required and Enteric Methane Emission Factor for Dairy Cattle

Table 2 shows the average required values energy by season for the different categories of dairy cattle in intensive, semi-intensive and extensive production systems. The NEm required in all animal categories was higher when the system was intensive and was lower when the animals were in an extensive system in the categories of both groups of heifers and calves (after weaning until 12 months of age). The NEg required for animals was 48% higher on average for the intensive system than for the rest of the production systems. In terms of NEl, cows in the intensive system required 3.7 times more NEl (83 MJ/d) than cows in the semi-intensive and extensive systems (22.5 MJ/d, on average). In all three production systems, non-lactating cows had higher NEp requirements than lactating cows or heifers from 15 to 24 months of age (3.8, 2.6 and 3 MJ/d, respectively). The relationship between NEm and DE for all categories and for all systems was 0.5, while the relationship between NEg and DE ranged from 0.2 to 0.4.

The GE requirements of dairy cows in the intensive system were 128 MJ/d higher on average than the other two production systems (377 vs. 249 MJ/d, on average). Likewise, non-lactating cows and pre-weaned calves have slightly higher required GE values than the other cattle systems. In addition, the diet received by heifers aged 15–24 months in the semi-intensive system had lower required GE values than the diet of heifers in the intensive and extensive systems (125 vs. 169 MJ/d). The highest Ym values were reported for non-lactating cows, both groups of heifers, calves and pre-weaning calves in the extensive system (6.8%), while the lowest Ym values were obtained for lactating cows in the intensive system (6.1%).

The EF was higher in lactating cows in the intensive system than in the semi-intensive and extensive systems (151 vs. 105 kg CH_4/head). On average, non-lactating cows had 1.66 times less EF than cows in the production stage. The EF in the heifers aged 12 to 15 months was equal for the intensive and extensive systems (101 kg CH_4/head/year), and lower for the semi-intensive system (74.2 kg CH_4/head/year). In calves prior to weaning, the EF is on average 55% less than for calves in the extensive and semi-intensive systems. The EF at the national level for Peruvian dairy cattle by animal category is presented in Table 2. Lactating cows presented the highest annual EF values, followed by the group of heifers from 12 to 15 months of age, non-lactating cows and heifers from 15 to 24 months of age, while animals in the rearing stage and calves prior to weaning presented the lowest values for EF.

Table 2. Average required energy values for the different categories of dairy cattle in intensive, semi-intensive and extensive production systems and their respective emission factor.

System/Animal Category	NEm (MJ/d)	NEa (MJ/d)	NEg (MJ/d)	NEl (MJ/d)	NEw (MJ/d)	NEp (MJ/d)	REM	REG	GE (MJ/d)	Ym (%)	EF (Kg CH_4/Head/Year)
Intensive system											
Lactating cows	49.4	0	N/E	82.9	0	3.5	0.5	N/E	377.8	6.1	151.8
Non-lactating cows	43.5	0	N/E	N/E	0	4.3	0.5	N/E	159.3	6.6	69.5
Heifers (females 15 to 24 months of age)	32.9	0	18.8	N/E	0	3.3	0.5	0.3	232.4	6.6	101.3
Heifers (females 12 to 15 months of age)	26.1	0	14	N/E	0	N/E	0.5	0.3	169	6.6	73.5
Calves (after weaning until 12 months of age)	17.4	0	9.1	N/E	0	N/E	0.5	0.3	111.3	6.6	48.4
Pre-weaned calves	8.3	0	2.8	N/E	0	N/E	0.5	0.4	30.6	4.3	8.6
Semi-intensive system											
Lactating cows	42.2	7.2	N/E	25.7	0	2.5	0.5	N/E	246.1	6.4	105.9
Non-lactating cows	36.6	6.2	N/E	N/E	0	3.7	0.5	N/E	158.9	6.6	69.7
Heifers (females 15 to 24 months of age)	27.9	4.7	8.2	N/E	0	2.8	0.5	0.3	168.8	6.6	74.2
Heifers (females 12 to 15 months of age)	21.3	3.6	6.5	N/E	0	N/E	0.5	0.3	125.3	6.6	54.9
Calves (after weaning until 12 months of age)	13.8	2.3	4.7	N/E	0	N/E	0.5	0.3	82.2	6.6	35.8
Pre-weaned calves	7.8	1.3	2	N/E	0	N/E	0.5	0.3	38.9	6.3	16.3
Extensive system											
Lactating cows	38.6	13.9	N/E	19.4	0	1.7	0.5	N/E	252	6.4	105.7
Non-lactating cows	33.5	11.8	N/E	N/E	0	3.4	0.5	N/E	180.6	6.8	81.3
Heifers (females 15 to 24 months of age)	28.6	10	9.0	N/E	0	2.9	0.5	0.3	223.7	6.8	101
Heifers (females 12 to 15 months of age)	21.3	7.5	7.3	N/E	0	N/E	0.5	0.3	169.4	6.8	76.3
Calves (after weaning until 12 months of age)	13.3	4.7	4.2	N/E	0	N/E	0.5	0.3	96.6	6.8	43.2
Pre-weaned calves	7.4	2.7	1.9	N/E	0	N/E	0.5	0.3	48.8	6.8	22

Table 2. *Cont.*

System/Animal Category	NEm (MJ/d)	NEa (MJ/d)	NEg (MJ/d)	NEl (MJ/d)	NEw (MJ/d)	NEp (MJ/d)	REM	REG	GE (MJ/d)	Ym (%)	EF (Kg CH_4/Head/Year)
National average [1]											
Lactating cows	42.7	7.9	N/E	38.2	0.0	2.5	0.5	N/E	282.6	6.3	117.8
Non-lactating cows	37.2	6.7	N/E	N/E	0.0	3.7	0.5	N/E	167.3	6.7	74.1
Heifers (females 15 to 24 months of age)	29.5	5.5	11.3	N/E	0.0	3.0	0.5	0.3	206.2	6.7	91.4
Heifers (females 12 to 15 months of age)	22.5	4.1	8.8	N/E	0.0	N/E	0.5	0.3	153.4	6.7	67.9
Calves (after weaning until 12 months of age)	14.5	2.6	5.7	N/E	0.0	N/E	0.5	0.3	95.2	6.7	41.9
Pre-weaned calves	7.8	1.5	2.2	N/E	0.0	N/E	0.5	0.3	40.5	6.0	16.5

Abbreviations: [1] Value generated from the proportion observed by production system based on the data generated in the present study (26% intensive system; 36% semi-intensive; 38% extensive). NEm: net energy of metabolism; NEa: net energy of activity; NEg: net energy of growth; NEl: net energy of lactation; NEw: net energy of work; NEp: net energy of pregnancy; REM: ratio of net energy available in diet for maintenance to digestible energy; REG: ratio of net energy available for growth in a diet to digestible energy consumed; DE: digestible energy; GE: gross energy; Ym: methane conversion factor; EF: enteric methane emission factor; CH_4: methane; N/E: not estimated.

3.3. Uncertainty Determination

Table 3 shows the two types of uncertainty (activity data or parameters and emission factor) and the combination of them with their interpretation. In most of the animal categories, except heifers from 12 to 15 months of age, the highest uncertainty values for EF were obtained in the extensive system, while the intensive system presented the lowest uncertainty values. In the three livestock systems, the parameters evaluated in the production cows presented the highest values for the uncertainty of the activity data (<22%), while in the non-lactating cows, the lowest percentages of uncertainty were obtained. The combined uncertainty obtained for the EF and activity data or average parameters for the dry and rainy seasons in the animal categories such as non-lactating cows, both groups of heifers, calves and pre-weaned calves was low or very low (between 9.4 and 18.72%), while the uncertainty generated for the category of lactating cows was low or medium, with values between 22.24 and 26.72%.

Table 3. Uncertainty of the enteric methane emission factor by production system.

System/Animal Category	Uncertainty EF (%)	Uncertainty of Activity Data (%)	Combined Uncertainty (%)	IPCC Interpretation
Intensive system				
Lactating cows	0.57	26.71	26.72	Medium
Non-lactating cows	1.11	9.33	9.40	Very low
Heifers (females 15 to 24 months of age)	1.63	10.95	11.07	Very low
Heifers (females 12 to 15 months of age)	1.66	10.50	10.63	Very Low
Calves (after weaning until 12 months of age)	1.93	11.77	11.93	Very low
Pre-weaned calves	0.74	12.98	13.00	Low
Semi-intensive system				
Lactating cows	2.31	22.12	22.24	Low
Non-lactating cows	2.83	12.74	13.05	Low
Heifers (females 15 to 24 months of age)	5.92	15.95	17.01	Low
Heifers (females 12 to 15 months of age)	5.46	14.42	15.42	Low
Calves (after weaning until 12 months of age)	4.11	14.91	15.47	Low
Pre-weaned calves	5.24	12.80	13.83	Low
Extensive system				
Lactating cows	2.50	24.44	24.57	Medium
Non-lactating cows	3.37	13.14	13.56	Low
Heifers (females 15 to 24 months of age)	5.03	16.09	16.86	Low
Heifers (females 12 to 15 months of age)	7.85	15.79	17.63	Low
Calves (after weaning until 12 months of age)	5.15	18.00	18.72	Low

Table 3. *Cont.*

System/Animal Category	Uncertainty EF (%)	Uncertainty of Activity Data (%)	Combined Uncertainty (%)	IPCC Interpretation
Pre-weaned calves	5.99	17.30	18.31	Low
National average [1]				
Lactating cows	1.93	24.20	24.29	Medium
Non-lactating cows	2.59	12.01	12.29	Low
Heifers (females 15 to 24 months of age)	4.47	14.70	15.41	Low
Heifers (Females 12 to 15 months of age)	5.38	13.92	15.01	Low
Calves (after weaning until 12 months of age)	3.94	15.27	15.78	Low
Pre-weaned calves	4.36	14.56	15.32	Low

Abbreviations: [1] Value generated from the proportion observed by production system based on the data generated in the present study (26% intensive; 36% semi-intensive; 38% extensive). CH_4: methane. EF: enteric methane emission factor.

4. Discussion

4.1. Characterization of the Systems and Energy Values

The type of production system has a direct effect on the productive parameters measured; such is the case of live weight or weight gain, where the animals in the intensive system had a better productive response. This result is associated with the fact that feed digestibility was higher in the intensive system than in the other two production systems, either because of better-quality forage (lower cell wall content) or because of the amount of grain or agro-industrial supplement ingested. This means that there is a greater amount of nutrients available to be absorbed and available for animal performance [26]. This is corroborated by the data reported in the NEg for both groups of heifers, calves and pre-weaned calves, where the NEg in the intensive system is almost double that reported for the semi-intensive and extensive systems. Authors such as VandeHaar et al. [27] ratify the above by stating that more digestible feeds generally have higher energy densities. In addition, NEg was calculated considering data such as adult weight, which is significantly higher in the intensive system due to the predominant breed in these farms.

In the pregnancy percentage parameter, it was observed that the intensive systems resulted in a higher number of pregnant animals than the semi-intensive and extensive systems, partly due to the fact that these systems have artificial insemination programs supported by specialized technical personnel. In addition to the above, the animals in these intensive systems have a better balance of protein and carbohydrates, due to the fact that agro-industrial and grain supplements and better-quality forages (<65% NDF) are part of their regular diet, resulting in a greater NE destined for pregnancy. This is corroborated by Rodney et al. [28] and Bisinotto et al. [29], who state that a better balance of nutrients and energy in the first 4 weeks of lactation improves oocyte quality and thus increases the probability of pregnancy.

Like pregnancy rate, milk production was higher in intensive systems, in part because genetic, environmental, physical and management factors positively influenced cows during lactation [30] and caused a higher percentage of total feed intake to be used for milk production rather than for cow maintenance [27].

The percentage of fat in milk was higher for cows in semi-intensive and extensive systems; this is because these systems base their diets on pastures, which provide high amounts of fibrous carbohydrates that, when degraded in the rumen, produce acetic acid and butyric acid that are used for the synthesis of milk fat in the mammary gland [31]. According to Erickson and Kalscheur [32], low NDF contents in the diet (<25% NDF for

25 kg milk production), small particle size and a feed intake that is highly degraded or a high concentration of unsaturated fats can produce incomplete biohydrogenation in the rumen, which negatively affects milk fat synthesis, which explains what happened in the intensive system.

It can be seen that required GE values are higher in lactating cows (0.94–1.01 Mcal/lb) compared to non-lactating cows (0.48 Mcal/lb), regardless of the dairy cattle production system [21]. This is mainly due to the higher energy level demanded for milk production. Regarding the other categories, it is also observed that as the animal grows, its required GE values are higher, regardless of the dairy cattle production system [21]. This is because, as the animal's live weight increases, so does its energy demand for muscle, bone and organ development.

4.2. Emission Factor and Uncertainty

The highest average values of enteric methane EF at the national level were for lactating cows (118 kg CH_4/head/year), followed by those found for heifers from 15 to 24 months of age, non-lactating cows, heifers from 12 to 15 months of age, calves and pre-weaned calves (88, 74, 64, 41 and 15 kg CH_4/head/year, respectively); the above trend is mainly due to factors such as live weight and daily dry matter intake. The above data obtained from seven Peruvian regions have an acceptable representativeness with respect to the national average in terms of the total number of lactating cows and total milk production.

When comparing our results with the values reported by other authors or entities that used IPCC equations (TIER II), it is observed that the values are similar. For example, the annual GHG report of the agricultural sector (RAGEI) of Peru for the year 2019 estimated an EF of enteric CH_4 for dairy lactating cows of 105.19 kg CH_4/head/year [1], a value like the one reported in the present study, whose values entered into the formulas were obtained from expert judgment or digital platforms. Likewise, authors such as Van Hyfre [33], Lermo [34] and Ruiz et al. [35] reported values of 153, 985 and 116.8 kg CH_4/head/year for lactating cows in intensive systems. As for the extensive system, Salas et al. [36] and Aliaga [37] used equations to calculate values of 105.8 and 120.4 kg CH_4/head/year, respectively.

Regarding enteric methane EF reported for lactating cows in the semi-intensive system, our study reported values of 105.9 kg CH_4/head/year, which are close to those found by Alvarado et al. [38] and Müller [39] when using the SF_6 technique in the inter-Andean and tropical valleys (109.5 and 87.6 kg CH_4/head/year, respectively). A similar situation is seen for the case of lactating cows in extensive systems, where our values were between the ranges reported by Salas et al. [36] and Medrano [40] (87.6 and 131.4 kg CH_4/head/year, respectively) for the Peruvian high Andean zone.

Variables such as quantity and quality of milk produced have a significant impact on enteric methane emissions; these variables are related to the nutrient content of the diet, digestibility and energy metabolism [41]. In other words, cows with high milk production have higher energy requirements, thus increasing their dry matter intake and thus increasing net methane emissions. However, when evaluating the emission intensity (methane per unit of product), intensive systems have lower values than the data reported for semi-intensive and extensive systems. This is in line with what was reported by deSouza et al. [42], Carrillo-Hernández et al. [43] and Arndt et al. [44], who state that better grazing management, such as decreasing forage maturity, supplementing with agro-industrial by-products and increasing feed intake, has the potential to reduce methane emission intensity by an average of 12%.

The category of lactating cows had the highest uncertainty values for activity data, mainly due to the largest divergence observed in the milk production values (kg/cow milking/day) established by the expert panel. In the 2016 National Greenhouse Gas Inventory for Peru, a combined uncertainty of 31.35% was reported for total CH_4 emissions transformed to Gg CO_{2eq} in the enteric fermentation category for dairy cows [1]. In South American countries, this value is very variable; for example, in Chile the combined uncertainty for CH_4 in the dairy cow component was 48% for the year 2020 [45], while in Uruguay, this value was 20.6% [46]. The aforementioned uncertainty values for the category of cows in production highlight the need to prioritize efforts to improve the accuracy of emission factor data. This includes the development of new strategies to optimize the methodology used, with the aim of establishing more effective mitigation policies based on sound data in the future.

5. Conclusions

At the national level, the category of lactating cows obtained the highest EF with 117 kg CH_4/head/year, followed by the values found for heifers from 15 to 24 months of age (91 kg), non-lactating cows (74 kg), heifers from 12 to 15 months of age (67 kg), calves (after weaning until 12 months of age) (62 kg) and pre-weaned calves (16 kg). Likewise, the highest EF was reported for lactating cows in the intensive system at 151 kg CH_4/head, which was 46.8 kg CH_4/head more annually than those emissions reported in the semi-intensive and extensive systems for the same animal category.

The combined uncertainty in animal categories such as dry cows, both groups of heifers, calves and pre-weaned calves was low or very low (between 9.4 and 18.72%), while the uncertainty generated for the category of lactating cows was low or medium with values between 22.24 and 26.72%.

More accurate estimation of enteric CH_4 and other GHG emissions, together with an appropriate regulatory framework, active participation of livestock stakeholders and a cost–benefit assessment, will help to create environmental policies tailored to the specific needs of each region, which should focus on sustainable livestock practices, ecosystem conservation, certification, financing and education.

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Conflicts of Interest: The authors declare no conflicts of interest.

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