# The Tier 2 predictive model is useful for estimating enteric methane emissions from dairy cattle at farm level in Spain

GHASAQ S. MSHARY[1,2], RODRIGO MUIÑO[2], JOAQUIN HERNANDEZ[2*], JOSÉ LUIS BENEDITO[2], ELENA NICEAS MARTINEZ[2], CRISTINA CASTILLO[2]

[1] Ghasaq S. Mshary, Department of Physiology, Chemistry and Pharmacology, College of Veterinary Medicine, AL-Muthanna University, Samawa, Iraq.
[2] Department of Animal Pathology, Faculty of Veterinary, Campus Terra-IBADER, University of Santiago de Compostela, 27002 Lugo, Spain

## SUMMARY

Globally, animal agriculture is a major source of greenhouse gases (GHGs) emissions. Various institutions such as the Intergovernmental Panel on Climate Change (IPCC), estimate that livestock accounts for 17% of global anthropogenic GHG emissions. In Spain, livestock farming, including enteric $CH_4$ production, accounted for 9.1% of total greenhouse gas emissions in 2020. Since ruminants are the highest contributors, there are strategies to reduce their impact, such as improving the feeding and management of ruminants. When estimating GHGs, there are many methods to choose from, each aimed at getting accurate and precise results for the emissions of each livestock breeding. These methods improved over time, moving towards more advanced approaches. The selection of the methodology falls into two types: 1) methods based on observed emissions data (also called direct methods); and 2) methods based on calculation procedures that include emission factors (EF) (called indirect methods). Indirect methods are the most suitable for measuring enteric $CH_4$ emissions under on-farm conditions and with large numbers of animals. In this context and from a clinical point of view, the predictive equations developed by the International Panel of Climate Change (IPCC) in its various updates are emerging. The IPCC guidelines highlight the use of the Tier 2 approach focusing on the $CH_4$ conversion factor (Ym, %) and gross energy (GE) of the ration for the calculation. Even if there is a lack of studies on this subject in Spain, however, investigations using this view have been carried out in many countries. Consequently, it is not possible to determine how much enteric $CH_4$ is produced by cattle and what possible corrective measures are adequate, according to the particularities of the Spanish agricultural sector.

This review aims to help veterinarians working on livestock farms assess enteric $CH_4$ emissions, in close collaboration with nutritionists based on data provided by the IPCC. Only then it will be possible to identify the positive and negative aspects of each farm and look for nutritional options to reduce emissions without compromising farm productivity, while addressing environmental concerns.

## KEY WORDS

IPCC, Tier-2, Greenhouse gas, $CH_4$, Cattle.

## ABBREVIATIONS:

BW (body weight); $CH_4$ (methane); CMO (Common Market Organization ); CP (Crude protein); DE (digestible energy); DMI (Dry matter intake); EE (Ether extract); EF (emission factor); EU (European Union); GHGs (greenhouse gases); GE (gross energy); IPCC (Intergovernmental Panel on Climate Change); $CH_4$-EF ($CH_4$ emission factor); MAPA (Spanish Ministry of Agriculture, Fisheries and Food); MFA (milk fatty acids); SEI (Spanish System of Inventory and Projections of Emissions to the Atmosphere); TMR (Total Mixed Ration); UNEP (United Nations Environment Programme); WMO (World Meteorological Organization); Ym (%) ($CH_4$ conversion factor).

Corresponding Author:
Joaquín Hernández (joaquin.hernandez@usc.es)

## INTRODUCTION

The European Union (EU) is a significant producer of milk and dairy products as part of the Common Market Organization (CMO). All EU countries produce milk, which accounts for a substantial portion of the value of EU agricultural production. EU milk production is estimated at around 155 million tons per year (CMO). The dairy cattle sector in Spain holds great economic importance as the third most significant livestock production sector, following the pig and beef sectors. Over the years, it has adapted to agricultural market challenges and foreign competition by integrating technological and structural advancements. This sector significantly contributes to maintaining the rural environment, economic diversification, and population settlement in areas where other economic activities may not be feasible. Additionally, dairy farms located in rural areas play a vital role in preventing depopulation, creating both direct and indirect employment opportunities, and revitalizing rural communities [1].

The dairy cattle production industry is currently facing a significant challenge due to the rise in $CH_4$ emissions attributed to enteric fermentation. These emissions, coupled with gases produced from the fermentation of cattle manure, contribute to the overall increase in greenhouse gases (GHG). Studies indicate that the livestock sector accounts for up to 17% of total anthropogenic $CH_4$ emissions globally. In Spain, a 2022 report from the Ministry for Ecological Transition and the Demographic Challenge [2] revealed that in 2020, livestock's enteric fermentation contributed 16.085 kt CO2-eq in net emissions. This marked a 12.0% increase from 1990 and a 0.5% increase from 2019. Table 1 illustrates the emission trends, categorizing the highest contributors as dairy and beef cattle.

Over the historical series, beef cattle have gained importance in the total category, from 39% in 1990 to 57% in 2020, at the expense of dairy cattle emissions (from 24% to 16%). In summary, the dairy sector's reduction in methane emissions is due to three factors. Firstly, improved production efficiency. Secondly, advanced manure management. And thirdly, a focus on sustainability. In contrast, the beef sector's increase can be attributed to two main reasons. Firstly, there are higher cattle numbers than before. And secondly, the adoption of similar efficiency measures is slower. These two herds, together with sheep, account for about 90 % of the total emissions of the livestock sector.

$CH_4$ has a relatively short lifespan of 12.2 years [3] and is released alongside other gases during the digestive process in an animal's gastrointestinal tract, specifically the reticulo-rumen and intestine, as well as through methanogenic processes in manure. It is currently recognized as a short-term climate enhancer. Despite its short atmospheric lifetime and lower emission quantities compared to $CO_2$, its heat-trapping potential is 28 times greater than $CO_2$ and $N_2O$ [4]. There are differing views on the extent of livestock's contribution to global $CH_4$ emissions. Studies analyzing the isotopic composition of $CH_4$ in the atmosphere, ice cores, archived air, and data from bottom-up and top-down approaches suggest that the post-2006 surge in $CH_4$ emissions is primarily driven by increases in microbial $CH_4$ [5] (see Figure 1).

Microbial emissions are due to methane-generating microbes (methanogens) found in anaerobic environments such as natural wetlands and rice paddies, oxygen-poor freshwater reservoirs (such as dams), digestive systems of ruminants, and organic waste deposits (such as manure, sewage, and landfills). This is in line with the report prepared by the Spanish Ministry for Ecological Transition and the Demographic Challenge [2], which considers that almost half of the emissions in the Spanish farming industry are generated using fertilizers and soil management, while the other half is caused by livestock farming (enteric fermentation and manure management). Ruminant species, mainly cattle, have the highest $CH_4$ emission rates, while poultry has almost negligible $CH_4$ release. On the other hand, monogastric animals like pigs fall between these two extremes, as the microbial density in their stomach and small intestine

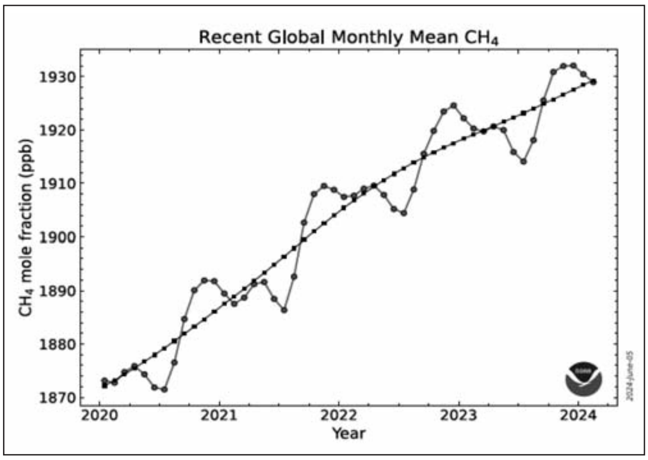


**Figure 1** - Global trend in $CH_4$. The line with circles is globally averaged monthly mean values centered on the middle of each month. The line and squares show the long-term trend (in principle, like a 12-month running average mean) [5].

is limited.

Spain has a well-established legal framework for creating national emission inventories. The General Bureau for Biodiversity and Environmental Quality is the main authority responsible for the Spanish System of Inventory and Projections of Emissions to the Atmosphere (SEI), which monitors greenhouse gases and atmospheric pollutants.

However, the livestock sector has significant gaps in its inventory systems due to its unique characteristics, unlike other industries. Agriculture and livestock are considered less energy-intensive sectors. While many efforts have been made to measure and address issues in livestock management, the lack of established reference values, according to European Community regulations, leaves veterinary professionals unsure about how to determine these values under different field conditions. When estimating greenhouse gases, there are many methods to choose from, each aimed at getting accurate and precise results for the emissions of each activity. These methods are meant to improve over time, moving towards more advanced approaches. The selection of the methodology falls into two types: 1) Methods based on observed emissions data; and 2) Methods based on calculation procedures that include emission factors (EF).

In the 2030 scenario, one proposed way to reduce GHG emissions is by controlling enteric fermentation through dietary modifications in the livestock sector. Currently, the carbon footprint of dairy farms is measured in kilograms of carbon dioxide equivalent per liter of milk ($KgCO_2/L$), with 1 Kg of $CO_2$ per liter of milk considered optimal. In France, the sector has introduced a differentiated label that identifies farms with emissions levels below 0.8 kg $CO_2$ per liter of milk. Around 6.000 farms have already registered for the label, known as *Bas Carbone* [6].

**Table 1** - $CH_4$ emissions (in kilotons $CO_2$ equivalent) from enteric fermentation cattle.

| | 1990 | 2005 | 2015 | 2019 | 2020 |
|---|---|---|---|---|---|
| **Dairy cattle** | 3397.1 | 2788.0 | 2642.7 | 2540.4 | 2528.4 |
| **Beef cattle** | 5581.3 | 8341.6 | 8352.0 | 9068.1 | 9121.4 |

## MEASURING ENTERIC $CH_4$ IN CATTLE: CURRENT METHODS

In this context, we need to consider the role of cattle in anthropogenic gas emissions and the necessity of creating inventories of livestock $CH_4$ emissions on both a national and global scale. Sources of uncertainty in $CH_4$ emissions from cattle include animal numbers, feed intake, diet composition, breed, Physiological stage and enteric $CH_4$ emission intensity [7]. The most used techniques for estimating these emissions are respiration chambers, the sulfur hexafluoride ($SF_6$) tracer technique, and the automated head-chamber system (GreenFeed). All three methods have been used successfully in numerous experiments with dairy or beef cattle in different controlled environmental conditions. However, studies comparing these techniques have reported inconsistent results. To improve the accuracy of predictions, the data sets utilized should cover a broad range of diets and production systems both regionally and globally [8].

Despite the varying precision of these techniques, two factors can make these methods impractical at times: 1) the potential stress placed on animals due to handling, which can alter the parameters being measured, and 2) the availability of farms for carrying out such measurements, especially if the goal is to conduct measurements on field conditions which doesn't have the controlled monitoring standards of research centers. The direct measurement of methane emissions from cattle under field conditions presents several disadvantages, including high costs, labor intensity, and difficulty with grazing animals, which complicates controlling their environment and behavior. Additionally, methane emissions can vary significantly between individuals, and environmental factors such as temperature, humidity, and altitude can affect the measurements, introducing additional variability in the data. Furthermore, the number of animals to which these measurements can be applied is very limited, and the process often causes stress and rejection among the animals. In addition, not all livestock farmers would favor this kind of design, which could negatively affect productivity, even if it effectively contributes to reducing $CH_4$ emissions [9].

There have been suggestions and applications of *indirect* methods to measure $CH_4$ EF. These methods are associated with lower accuracy and greater uncertainty in the emission data compared to the direct methods mentioned above. Changes in metabolic activities, differences in feed efficiency, and variations in ruminal fermentation can all influence the amount of $CO_2$ produced by the animal, thus modifying the predicted $CH_4$ emission [7, 10]. However, it uses easily accessible on-farm parameters such as ration or animal characteristics like live weight and dry matter intake (DMI), or milk production [11].

DMI is a crucial factor in predicting $CH_4$ emissions from livestock. Researchers have studied the relationship between measured $CH_4$ production with DMI and neutral-detergent fiber (NDF). It has been found that the correlation between $CH_4$ emissions and DMI is strong when there is a wide range of DMI and weak when the range of DMI is narrower. The dairy NRC (2001) model [12] uses the cow's metabolic body weight, milk yield, and stage of lactation to predict DMI. It is also important to note that the estimation of DMI in dairy cattle on commercial farms is in any case a critical and uncertain process. Other studies have found that milk solids concentrations can be useful in predicting $CH_4$ emissions from dairy cattle. Moraes et al. [13] highlighted the significance of milk fat content as a key variable for predicting $CH_4$ emissions. Furthermore, Kandel et al. [14] discovered a moderate correlation between predicted $CH_4$ intensity (calibrated from $SF_6$ tracer data) and protein yield. However, additional studies have found that attempting to correlate different milk components with $CH_4$ values obtained from direct methods may not be reliable indicators of $CH_4$ emissions [15].

In the last ten years, researchers have been studying the use of milk fatty acids (MFA) as indicators of $CH_4$ emissions due to their direct connection to microbial digestion in the rumen. The mammary gland's *de novo* production of MFA primarily utilizes acetate (85% of de novo synthesized FA) along with β-hydroxybutyrate (10 to 15%) and a small amount of propionate to produce short-chain FA (C4, C6, and C8), most medium-chain FA (C10, C12, and C14), and about 60% of C16 [16, 17]. Numerous prediction equations have been developed to explain the relationship between milk fatty acids (measured using gas chromatography) and $CH_4$ production from the digestive system. However, the correlation index has varied between 47% and 95%, and the links between individual milk fatty acids and $CH_4$ production differ significantly [18]. These differences may stem from the direct $CH_4$ measurement technique and the way $CH_4$ emissions are expressed. Furthermore, Vanrobays et al. [19] discovered the correlations between $CH_4$ emissions and MFA change throughout lactation, providing further insight into the diverse findings in the literature.

To evaluate $CH_4$ emissions in on-farm settings, it is essential to utilize indirect methods that are suitable for large-scale applications. This is increasingly crucial due to the necessity of accurately determining GHGs emissions in diverse farming environments. Moreover, there is a rising requirement for the establishment of standardized baseline values to serve as a reference for implementing corrective strategies based on nutrition. The use of advanced statistical programs allows for the collection of reliable data related to animal health and productivity. These critical points enable specialists to take prompt and effective actions.

The GLOBAL NETWORK project (Global Network for the Development and Maintenance of Nutrition-Related Strategies for Mitigation of $CH_4$ and Nitrous Oxide Emissions from Ruminant Livestock 2014-2018) is an international collaborative initiative of animal scientists from all continents except Africa [20]. The database contains records of enteric $CH_4$ production, along with corresponding data on DMI, body weight (BW), GE, crude protein (CP), ethereal extract (EE), NDF, and ash. Additionally, it includes information on milk yield (MY) and concentrations of milk fat and crude protein. With these parameters and depending on the procedure used (direct or indirect) for the measurement of $CH_4$ emissions, different statistical models have been developed, with great variability in the results. In addition, studies indicate that although there are no significant differences in enteric $CH_4$ emissions between breeds of dairy cows with different genetic backgrounds, those with more *Bos taurus* genes present higher $CH_4$ emissions. Therefore, *B. taurus* x *B. indicus* genetic crosses should be considered for future trials, especially in the tropics [7].

In this context of uncertainty, and from a clinical point of view, the predictive equations developed by the International Panel of Climate Change (IPCC) in its various updates are emerging.

## WHAT IS THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) AND ITS RELEVANCE FOR ENTERIC $CH_4$ EMISSIONS?

The Intergovernmental Panel on Climate Change (IPCC) was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The United Nations General Assembly endorsed its creation that same year. The IPCC's mission is to provide policymakers with regular scientific assessments on climate change, covering topics such as the science of climate change, its social and economic impact, and potential response strategies. Since its inception, the IPCC has produced six comprehensive *Assessment Reports* and several other specialized reports, contributing significantly to international climate policymaking (https://www.ipcc.ch/about/history/). Since then, the IPCC has played a key role in institutionalizing this concept and is recognized as the leading authority on global climate science. The IPCC reports address various aspects of climate change, including the impact of livestock on the environment. Here are some key points from the IPCC reports related to livestock such as agriculture procedures or the significant role of livestock in climate change and the need for sustainable management and practices to mitigate their impact [21, 22].

**Tiers and $CH_4$ emission factors (EF-$CH_4$ kg CH4 head$^{-1}$ year$^{-1}$) calculations**

The IPCC guidelines classify the methodological complexity into different tiers (or levels) for estimating emissions of each greenhouse gas in mass units. These tiers are based on the amount of data required and the level of analytical complexity [23]. *Tier 1* is an empirical method that uses default EFs per head of livestock to calculate enteric $CH_4$ emissions.

The *Tier 1* method of the IPCC [24] for estimating total $CH_4$ emissions from enteric fermentation uses mainly *feed intake* (based on the energy requirements of the animal for maintenance and production), and, *conversion of feed energy to $CH_4$* (the rate at which feed energy is converted to methane depends on the quality of the feed, which generally is assessed in terms of digestibility for each region).

The applied formula to estimate total methane emissions from Enteric Fermentation applying *Tier 1* methods, following IPCC, is:

$$\text{Total } CH_{4\ \text{Enteric}} = \sum \text{E iP}$$

Where: Total $CH_{4\ \text{Enteric}}$ = total $CH_4$ emissions from Enteric Fermentation, Gg CH4 yr-1

$\sum$ E iP is the emissions for the ith livestock categories and subcategories based on production systems (P).

This formula calculates the total $CH_4$ emissions from enteric fermentation in livestock by multiplying the number of animals by the default emission factor provided by the IPCC.

To estimate methane emissions from enteric fermentation in bovines using the IPCC *Tier 2* method [24], several key variables are considered: *Animal population data,* animal characteristics ( like average body weight or milk production), *feed characteristics* (DMI or feed composition), *gross energy intake* (GE) (calculated on the average feed intake and the energy content of the feed), $CH_4$ conversion factor (Ym) ( provide by ICCP), and finally, *environmental factors* ( like temperature or housing). *Tier 2* is an enhanced method that requires information about animal categories, feeding, and production systems. The *Tier 3* approach is used when a country-specific methodology for enteric $CH_4$ emission estimation has been developed by the IPCC [24, 25].

*Tier-2* and *Tier-3,* known as *higher tier*, are generally considered more accurate than the default *Tier-1* approach due to their suitability for specific applications [7, 26-28]. The *Tier-2* method is recommended for countries with large livestock populations, using mostly national parameters related to feed diet, production characteristics, energy requirements, and energy/protein ratio. The precise data for each level of measurement or tier are shown in Figure 2. The IPCC in its various reports encourages the development of studies in different countries and management conditions to increase satisfactory inventories. Unfortunately, to our knowledge, very few studies have been carried out in Spain on this topic.

The enteric $CH_4$ conversion factor (Ym%) is a crucial specific value in these models. It provides accurate data on the inventory of EFs-$CH_4$. This value is related to the percentage of gross energy intake (GEI) and $CH_4$ production, considering the production system, type and age of livestock, and characteristics of feed available on the farm within a reasonable range of uncertainty [11, 29].

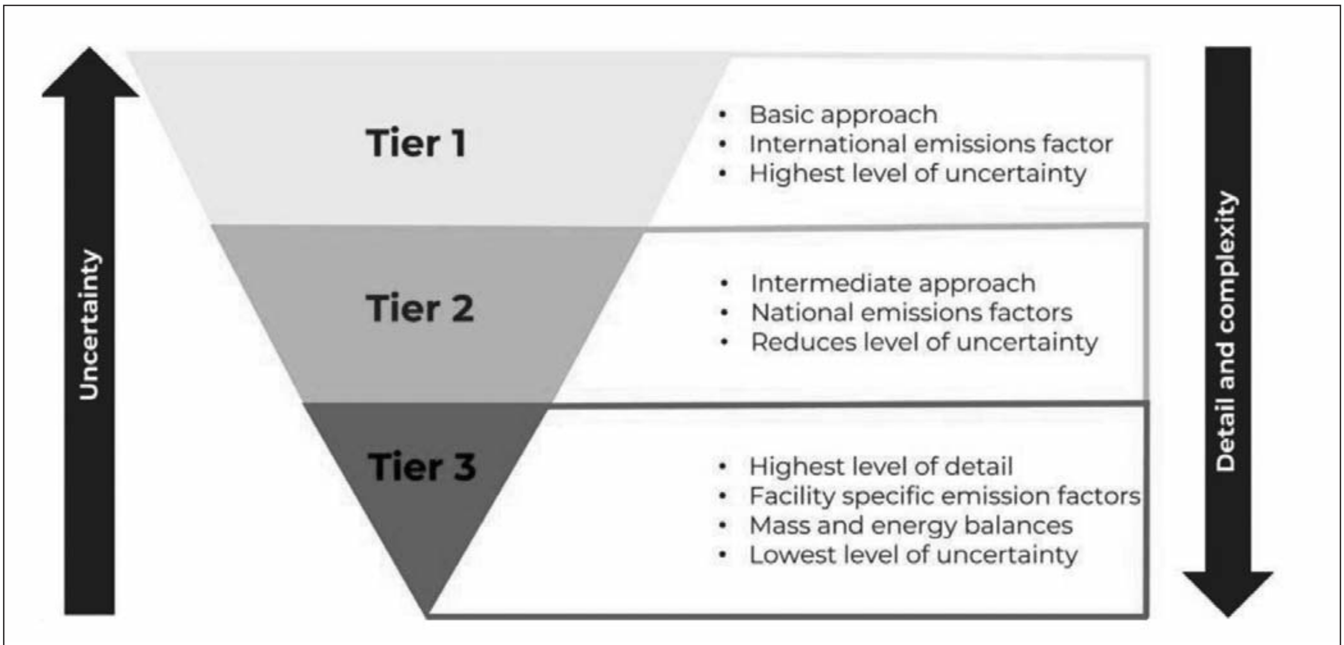


**Figure 2** - Tier methodological complexity [28]. Available at: https://www.agrecalc.com/home

Ym (%) is defined as the percentage of energy provided with the ration that is converted into $CH_4$ [29]. The energy provided with the ration that is converted into $CH_4$ depends on several factors such as animal production, as well as the quality and digestibility of the different diets, taking as a reference the total mixed ration (TMR) with an inverse relationship between Ym (%) and digestibility [30]. The calculation of the emission factor directly depends on Ym. Due to the high level of uncertainty in estimating Ym, it is relevant to improve the accuracy of this parameter in future studies. Researchers can determine site-specific Ym values through more thorough studies in areas where a Tier 3 approach is available, following IPCC guidelines. In regions where this level of information is not available, Tier 2 and the estimated Ym (%) can be used [11].

ICCP states that a *Tier-3* approach "could employ the development of sophisticated models that consider diet composition in detail, concentration of products arising from ruminant fermentation, seasonal variation in animal population or feed quality and availability, and possible mitigation strategies" [31].

Regarding the estimation of CH emissions from enteric fermentation in bovines using the IPCC *Tier-3* method, the main variables to be considered include animal population data (number of bovines categorized by age, sex, and production stage), animal characteristics (body weight, growth rates, and milk production), feed intake and composition (types and amounts of feed consumed, including forage, grains, and supplements, considering their digestibility and nutrient content), CH emission factors (specific emission factors), and environmental conditions (temperature, humidity, and altitude, which can affect feed intake and digestion efficiency).

The IPPC [24] has developed recommendations for the Ym factor, considering milk production, the level NDF in the diet, and their digestibility percentage. In cases where country- or region-specific $CH_4$ emission factor (Ym %) values are unavailable, it is viable to utilize estimations put forward by various studies [20, 32-33] that have contributed to the *IPPC Refinement* [25] for EF-$CH_4$ calculations. Recent studies have also adopted these assumptions [34]. All that is needed is to know in which subcategory the studied cows fall based on production, productive status, and feed quality (focused on digestibility, DE %) and NDF (% DMI). These references are listed in Table 2

Once the subcategory is selected, EF-$CH_4$ for each dairy cattle group can be calculated using the IPCC Tier 2 [24-25] approach based on gross energy intake (GEI) and Ym (%) as follows:

$$EF = \frac{[GE \times (Ym/100) \times 365 \text{ days})]}{55.65 \text{ MJ/kg } CH_4}$$

Where EF is the $CH_4$ emission factor (kg $CH_4$/head/year) and Ym represents the $CH_4$ conversion rate (%), which is the fraction of gross energy (GE) in feed converted to $CH_4$. The factor 55.65 (MJ/kg $CH_4$) is the energy content of methane.

The GE value is developed by several mathematical equations that consider factors such as energy for maintenance, pregnancy, lactation, and so on… Such complicated calculations are now carried out by sophisticated computer software designed to manage the information and predict the nutrient requirements and supply in each production situation, providing GE values according to the diet applied and production.

Veterinarians are now present on every farm to assess the quality of diets and ensure they meet production requirements. Utilizing the appropriate software platform is crucial for precise feed assessment, a key component of *smart farming*. In doing so, we aim to address the concerns of veterinarians, who are not nutritionists but are responsible for managing livestock farms, including the control of EF-$CH_4$.

## Implications for Methane Emissions and Sustainable Livestock Production

The Common Agricultural Policy (CAP) has undergone reform to align itself with the EU's sustainability objectives. This has entailed the introduction of so-called «eco-schemes» designed to encourage environmentally friendly farming practices. The aforementioned reforms are part of the broader *European Green Deal*, whose overarching goal is to achieve climate neutrality by 2050 [1, 2]. Furthermore, recent political action, in the form of the EU Climate Law, has sought to further integrate sustainability principles into agricultural policy, providing support for organic farming and renewable energy. De-

**Table 2** - Cattle $CH_4$ conversion factor (Ym, %) in different conditions and diets [25].

| Livestock category | Description | Feed quality digestibility (DE %) and NDF (% DMI ) | Ym (%) |
|---|---|---|---|
| Dairy cows | High-producing cows (>8500 kg/head/year) | DE ≥ 70<br>NDF ≤ 35 | 5.7 |
| | High-producing cows (>8500 kg/head/year) | DE ≥ 70<br>NDF ≥ 35 | 6.0 |
| | Medium-producing cows (5000-8500 kg/head/year) | DE → 63-70<br>NDF > 37 | 6.3 |
| | Low-producing cows (< 5000kg/head/year) | DE ≤ 62<br>NDF > 38 | 6.5 |
| | > 75% forage | DE ≤ 62 | 7.0 |
| Non-dairy and multi-purpose cattle | Rations of 75% high quality forage and or mixed rations | DE → 62-71 | 6.3 |
| | Feedlot (all other grains 0-15% forage) | DE ≥ 72 | 4.0 |
| | Feedlot (steam-flaked corn, ionophore supplement, 0-10% forage) | D E> 75 | 3.0 |

spite these developments, there remains several challenges and criticisms surrounding the practical implementation and the potential impact on smallholder farmers.

And finally, there is a significant correlation between enteric methane emissions and animal health outcomes [35]. A decline in animal health can result in diminished feed efficiency and modifications to digestive processes, which can markedly elevate enteric $CH_4$ emissions. Conversely, the improvement of animal health through the implementation of enhanced nutritional and management practices can lead to an increase in feed efficiency and a reduction in $CH_4$ production. It is therefore imperative to address health impairments to mitigate enteric $CH_4$ emissions and ensure more sustainable livestock production.

## CONCLUSIONS

This review aims to help veterinarians working on livestock farms to assess enteric $CH_4$ emissions, in close collaboration with nutritionists based on data provided by the Intergovernmental Panel for Climate Change (IPCC). By analyzing farm data at the local level, veterinarians can establish baseline values and compare them at the regional or national level. This approach allows a more accurate determination of enteric $CH_4$ emissions in the Spanish environment. Only then will it be possible to identify the positive and negative aspects of each farm and look for nutritional options to reduce EF-$CH_4$ without compromising farm productivity, while addressing environmental concerns.

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### Author Contributions
Investigation, writing original draft GSM EN CC; Conceptualization, Investigation, Writing/review and editing CC, JHB; Formal analysis JLB, RM. All authors have read and agreed to the published version of the manuscript.

### Conflict of Interest Statement
The authors declare no conflict of interest.

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