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Research article

Assessment of livestock greenhouse gases in Colombia between 1995 and 2015

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ABSTRACT

The livestock sector in Colombia significantly participates in national economic dynamics but makes significant worldwide contributions to greenhouse gas emissions. Hence, climate change mitigation in this sector is essential. This study aims to assess the greenhouse gas in the livestock sector. The results are reported in methane emissions (CH_4) and nitrous oxide (N_2O) from enteric fermentation, and N_2O by manure management based on the information from the Emission Database for Global Atmospheric Research (EDGAR), in all cases expressed as dioxide of carbon (CO_{2eq}). The emissions obtained from the EDGAR database for 2015 were proportional to the values of the National Inventory of Greenhouse Gases published by the Institute of Hydrology, Meteorology, and Environmental Studies (IDEAM) in 2016. Colombia is the 12th on global, 4th in America and 2nd in South America position by livestock GHG emission, and is the dominant source in all economic sector. The results showed higher records for CH_4 emissions during the years 2010 and 2015, while the N_2O emissions were higher during 2015. The regions with the highest emissions of CH_4 and N_2O corresponded to the northwestern area of Colombia. The Spearman correlation test showed a positive correlation between the CH_4 emissions, and the age groups studied. The post hoc analysis of the Kruskal–Wallis test showed a more significant influence on CH_4 emissions.

1. Introduction

The increase in anthropogenic activities has contributed to the variation in greenhouse gas (GHG) concentrations in the atmosphere; globally, between 1990 and 2010, net GHG increased by 35%, causing a positive climate forcing or warming effect, reflected in changes in ocean temperature, with increases from 0.65 °C to 1.06 °C, the melting of glaciers and Arctic thaw, an increase in warm days and nights, an increase in the frequency of heat waves in Asia, Europe, and Australia, variability in the distribution of rainfall, and an increase in the occurrence of extreme meteorological phenomena (Jose et al., 2016). From 1990 to 2015, the total warming effect of GHG from human activities increased by 37% (Jose et al., 2016; EPA, 2020a,b).

GHG are derived from natural and anthropogenic processes such as the burning of fossil fuels, changes in land use, deforestation, anaerobic decomposition of organic waste in landfills, biomass combustion, and agricultural and livestock practices (Jose et al., 2016; EPA, 2020a,b). The most important GHG are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases, such as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6), whose effects on climate change depend on three variables: concentration, lifetime in the atmosphere, and the global warming potential (GWP) of each gas (EPA, 2020a,b; Minanmbiente, 2020a,b).

In this context, CH_4 and N_2O play an important role in total GHG, according to the Intergovernmental Panel on Climate Change (IPCC). CH_4 contributes 15–20% of the total global emissions, and N_2O contributes 6% (Cheewaphongphan et al., 2019; Parra-Cortés et al., 2020; EPA, 2020a,b). Published records show increases in the concentrations of CH_4 in the atmosphere, largely attributed to anthropogenic emissions arising from livestock production, rice cultivation, and biomass burning (Jose et al., 2016).

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Table 1. Global warming potential.

Greenhouse gas	GWP			
	AR2 1995 (IPCC, 1995)	AR3 2001 (IPCC, 2001)	AR4 2007 (IPCC, 2007)	AR5 2014 (IPCC, 2014)
CH_4	21	23	25	28
N_2O	310	296	298	265

Data source: IPCC, 1995; IPCC, 2001; IPCC, 2007; IPCC, 2014.

The livestock sector is considered one of the main contributors to climate change. Therefore, the mitigation of climate change is highly priority for the agriculture sector worldwide (Baležentis et al., 2022). In livestock production systems, the sources of GHG come from land use, enteric fermentation, manure management, processing, and transport (Vac et al., 2013; Jose et al., 2016; Peng et al., 2016; Parra-Cortés et al., 2020). Enteric fermentation is a process that occurs in the digestive system of certain animals and generates CH_4 as a byproduct. Of the total CH_4 produced in the livestock sector, 95% is excreted by eructation, 89% is made in the digestive tract and eliminated by respiration, and 11% is eliminated via the anus (Ribeiro et al., 2015).

Regarding the indirect contribution of livestock to manure management, CH_4 emissions occur due to the anaerobic microbial decomposition of solid and liquid fecal matter and depend on factors such as the type of treatment or storage facility, environmental conditions, and manure composition (Opio et al., 2013). In general, animal waste generates 10–15% CH_4 (IDEAM, 2016), with cattle and pig manure having the highest emission potential (Centella et al., 2001).

Regarding N_2O emissions, the organic waste (feces and urine) generated by livestock production is responsible for approximately 18% of the total emissions of this gas worldwide (Pattey et al., 2005). Direct deposition of manure and urine of grazing animals in pastures (Berra and Finster, 2002) and indirect deposition from the volatilization of nitrogen excreted by animals (Blanco et al., 2011; Gerber et al., 2013) occur.

The global emissions of CH_4 by enteric fermentation and manure management from 2008 to 2017 were estimated to be in the range of 106–116 Tg CH_4yr^{-1}, equivalent to almost one-third of the global total anthropogenic emissions (Saunois et al., 2020). Approximately 12.5% of global GHG comes from the livestock sector, and 80% of emissions from agriculture are associated with the livestock sector. Around 36% of the global emissions of CH_4 and 64% of those of N_2O are attributed to the livestock production process (Nieto et al., 2014; Vac et al., 2013; Jose et al., 2016).

The bovine livestock is responsible for 28% of emissions, of which 95.46% of the CH_4 emissions by enteric fermentation correspond to cattle farming. Publications indicate that cattle production emits 81.77% of direct N_2O emissions from grazing cattle and 80% of indirect N_2O emissions from soils through cattle manure (Nieto et al., 2014). On the other hand, CH_4 emissions by cattle represent 43% of the total emissions in various dairy and beef supply chains worldwide (Gerber et al., 2013).

Latin America and the Caribbean contribute approximately 9% of GHG's total global anthropogenic emissions, producing 14% of the global CH_4 emissions. Publications indicate that Brazil (44.7%), Mexico (22.8%), Argentina (13.7%), and Colombia (7%) contribute large volumes of GHG (IDEAM, 2016; Benaouda et al., 2017).

In Colombia, the livestock sector is crucial for socioeconomic development (Anaya et al., 2010; IDEAM, 2016) and represents 88% of the national agricultural industry. At the national level, the agricultural sector contributes 6% of the gross domestic product (GDP), and livestock farming contributes 1.4% of the GDP (FEDEGAN, 2018). The Colombian livestock inventory between 2015 and 2019 showed an increase of 16.09%, represented by a growth of 4,383,380 heads of cattle (FEDEGAN, 2018).

Within the framework of the Paris Agreement and the process of updating the contribution determined at the national level of Colombia, where the goal for reducing GHG in Colombia will be 51% by 2030 (Minanmbiente, 2020a,b), it is important to assess the emissions associated with the livestock sector. Even more when according to Wilkes et al. (2020) affirmed that global scientific expertise in livestock GHG

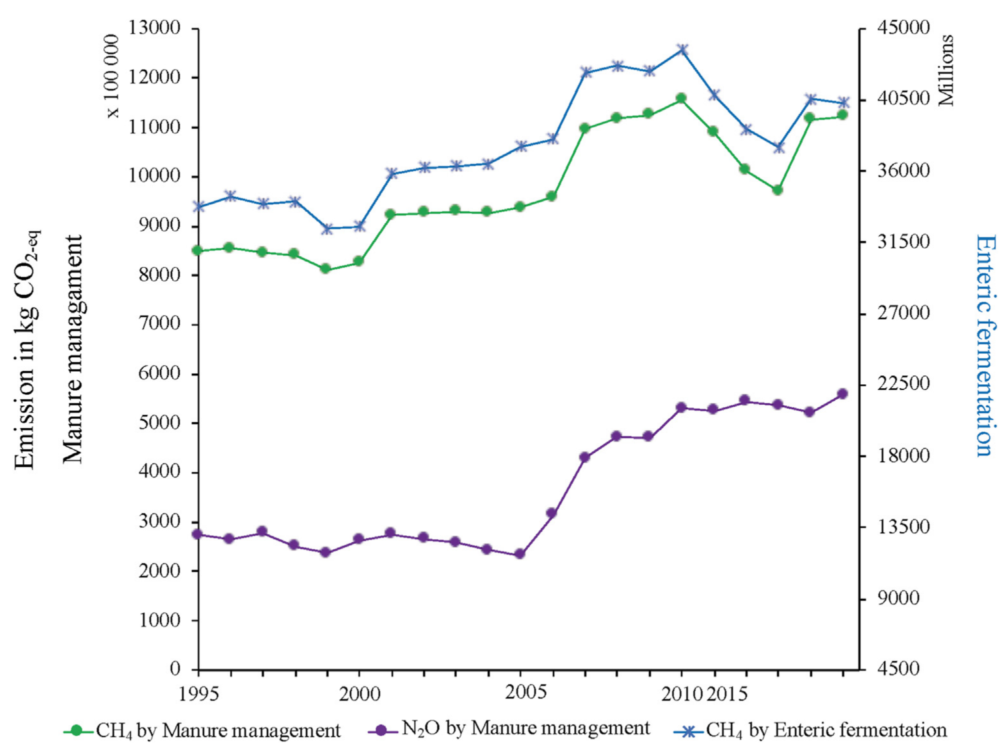

Figure 1. Emission of greenhouses gases during 1995–2015 in Colombian of CH_4 by emissions from enteric fermentation (blue line) and manure management (green line); and N_2O by manure management (purple line).

emissions has had limited engagement with public policy processes, leaving a gap related to the support countries to improve measurement, reporting and verification of data or specific needs for information in this sector.

Therefore, the objective of this research is to assess the emissions of GHG such as CH_4 and N_2O in Colombia from the EDGAR v5.0 database and the national cattle inventory to generate of information that facilitates the achievement of the goals proposed at the national level to combat climate change.

2. Data and methods

2.1. Database sources and study domain

Data collection for the research was performed through the consultation of national databases from The national bovine inventory was obtained from the National Agricultural Survey of the National Administrative Department of Statistics (DANE, for its acronym in Spanish) and the Colombian Federation of Livestock Farmers (FEDEGAN, for its acronym in Spanish), these institutes provided the national bovine inventory for 1995–2015, except for 1998, where the National Agricultural Survey was not carried out, indicated in File No. 2021313000576-1 of the DANE. In the same way, the data were downloaded from EDGAR v5.0. Which provides records of CH_4 by enteric fermentation and manure management, and N_2O by management of manure worldwide. The study domain is the Colombian territory.

EDGAR calculate the emissions using a technology-based emission factor approach consistently applied for all world countries, as summarized in the following formula:

$$EM_c(y,x) = \sum_{i,j,k} \left\lfloor AD_{C,i}(y) * TECH_{C,i,j}(y) * EOP_{C,i,j,k}(y) * EF_{C,i,j}(y,x) * (1 - RED_{C,i,j,k}(y,x)) \right\rfloor$$

where the emissions (EM) for a country C are calculated for each compound x on an annual basis (y) and sector (for i sectors, multiplying on the one hand the country-specific activity data (AD), quantifying the human activity for each of the i sectors, with the mix of j technologies (TECH) for each sector i, and with their decrease percentage by one of the k end-of-pipe (EOP) measures for each technology j, and on the other hand the country-specific emission factor (EF) for each sector i and technology j with relative reduction (RED) of the uncontrolled emission by installed decrease measure k.

According to IDEAM (2016), the guidelines of the IPCC in 2006 contemplate the methodological guidelines to develop estimates of direct emissions of CH_4 and N_2O generated by activities in different economic sectors; therefore, the estimation of emissions according to the IPCC Tier 2 methodology was performed by the conversion of GHG into equivalent emissions of CO_2 ($CO_{2\text{-eq}}$) using the GWP published in the IPCC climate change assessment reports. The GWP corresponding to each study period from 1995 to 2015 is listed in Table 1 (IPCC, 1995; IPCC, 2001; IPCC, 2007; IPCC, 2014).

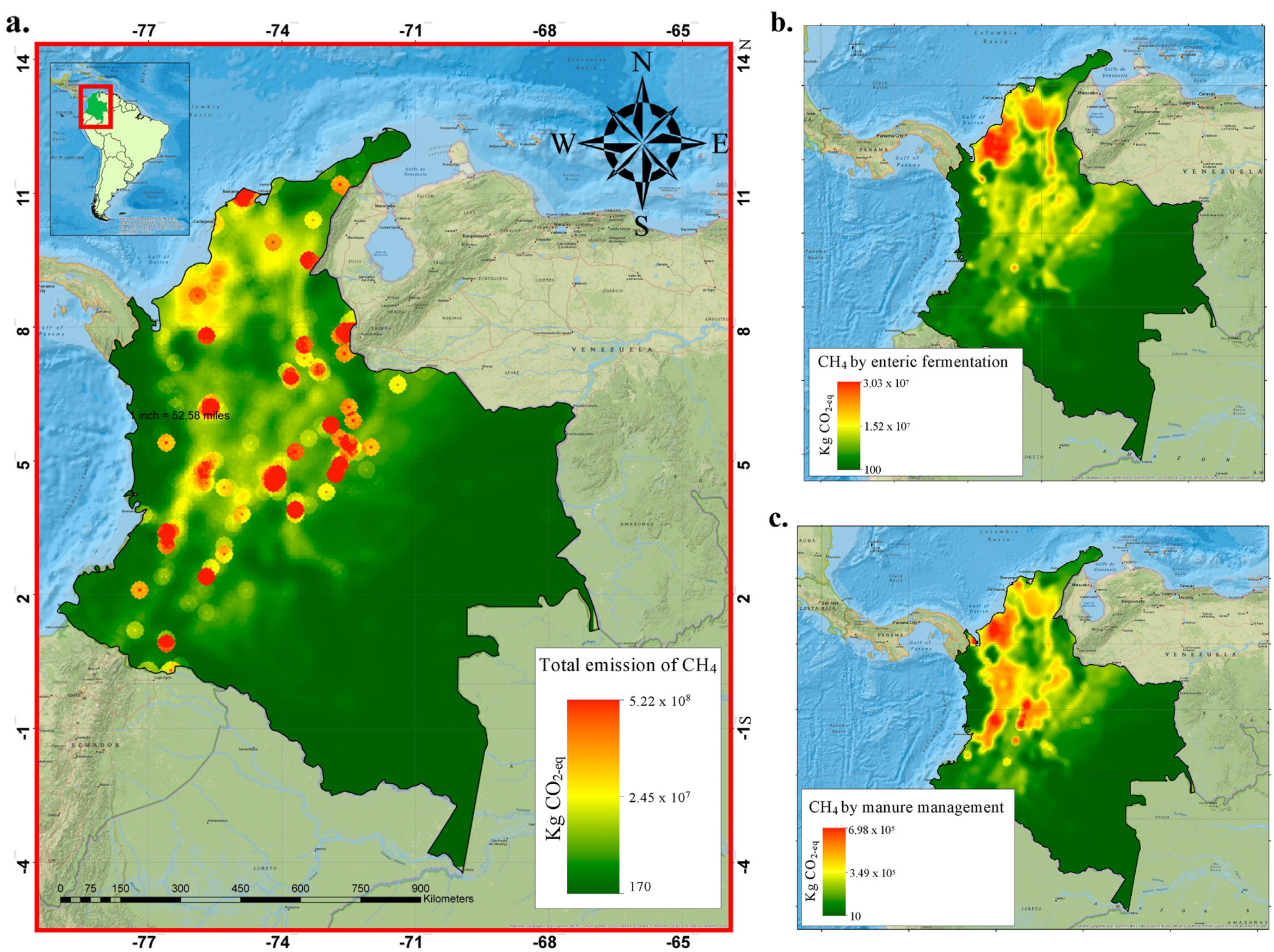

Figure 2. (a) CH_4 Emissions in 2015. (b) CH_4 Emissions from Enteric Fermentation in 2015. (c) CH_4 Emissions from Manure Management in 2015.

2.2. Statistical test

Information from the EDGAR v 5.0 database and the national bovine census of the National Agricultural Survey were used to determine the participation of the sources. The Shapiro–Wilk normality test was applied for the identified age groups, males, and females, and CH_4 emissions by enteric fermentation and manure management, and N_2O emissions by manure management. The age groups of the study correspond to males and females younger than 1 year, between 1 and 2 years, between 2 and 3 years, and older than 3 years from 1995 to 2015. As data did not follow a normal distribution, nonparametric tests were used. The Spearman correlation test was used to identify correlations in the variables, then the Kruskal–Wallis test was applied to identify the existence of statistically significant differences, and finally, a post hoc analysis was applied according to the methodology indicated in Field et al. (2012) to identify pairs of groups with differences. The statistical test was applied for two groups of data, Group 1 including the data from 1995 to 2005, and Group 2 including the data from 2006 to 2015; due to 2006, the classification of the survey included a new category, older than 3 years. Finally, the data were organized in a Microsoft Excel file and entered the ArcGIS program to generated the Colombia's maps emission of GHG under studies.

3. Results

3.1. Emissions

Figure 1 shows higher records of CH_4 emissions in 2010 and 2015, decreases in 2011, and increases from 2013 to 2015. For N_2O emissions by manure management, an increase is observed in the records from 1995 to 2005, with marked increases from 2005 to 2015 and the highest emissions reported in 2015.

The results show CH_4 emissions in the range of 177,522–5.22 $\times$ 10^8 kg of $CO_{2\text{-eq}}$. The areas of the country with the highest emissions records correspond to the northern and central zone of Colombia. The areas with the highest records of CH_4 emissions are Atlántico, César, Córdoba, Antioquia, Valle del Cauca, Cundinamarca, Casanare, and Boyacá. On the other hand, the southern zone reports low emission values with respect to the national total, as shown in Figure 2a.

The results from the 2015 report CH_4 emissions by enteric fermentation range from 105.63 to 3.03 $\times$ 10^7 kg of $CO_{2\text{-eq}}$ in the areas of Magdalena, Cesar, Sucre, and Córdoba. In the central zone, values lower than those in the northern zone are found, while the southern zone reports the lowest emission values according to Figure 2b. Likewise, Figure 2c shows that the 2015 CH_4 emissions by manure management range from 11.13 to 697884 kg of CO_2-eq. The highest records occur in the northwestern area of Colombia, with higher values in the areas of Sucre, Córdoba, Antioquia, and Valle del Cauca. The southern zone shows low emission values with respect to the total emissions recorded.

Figure 3a shows that the 2015 emissions of N_2O range from 87718.2 to 2.032 $\times$ 10^7 kg of CO_2-eq. The areas with the highest records correspond to the northern zone, especially in the departments of Magdalena, Sucre, Córdoba, and Cesar. The Department of Cundinamarca also reports high values of N_2O emissions. In general, the central zone reports lower emission values, and the southern zone reports the lowest emission values.

The records represented in the map of Figure 3b for 2015 show emissions of N_2O by manure management in the range of 0.0190858–927714 kg of CO_2-eq. Taking account the largest contributions of GHG correspond to Methane by enteric fermentation. On a global scale, Colombia is among the top 15 with the highest emissions worldwide, in the 12th position; likewise is 4th in America, and 2nd in South America. This denotes the importance of emissions associated with livestock (Figure 4a, b). To another hand, comparative emissions at the national level by the different

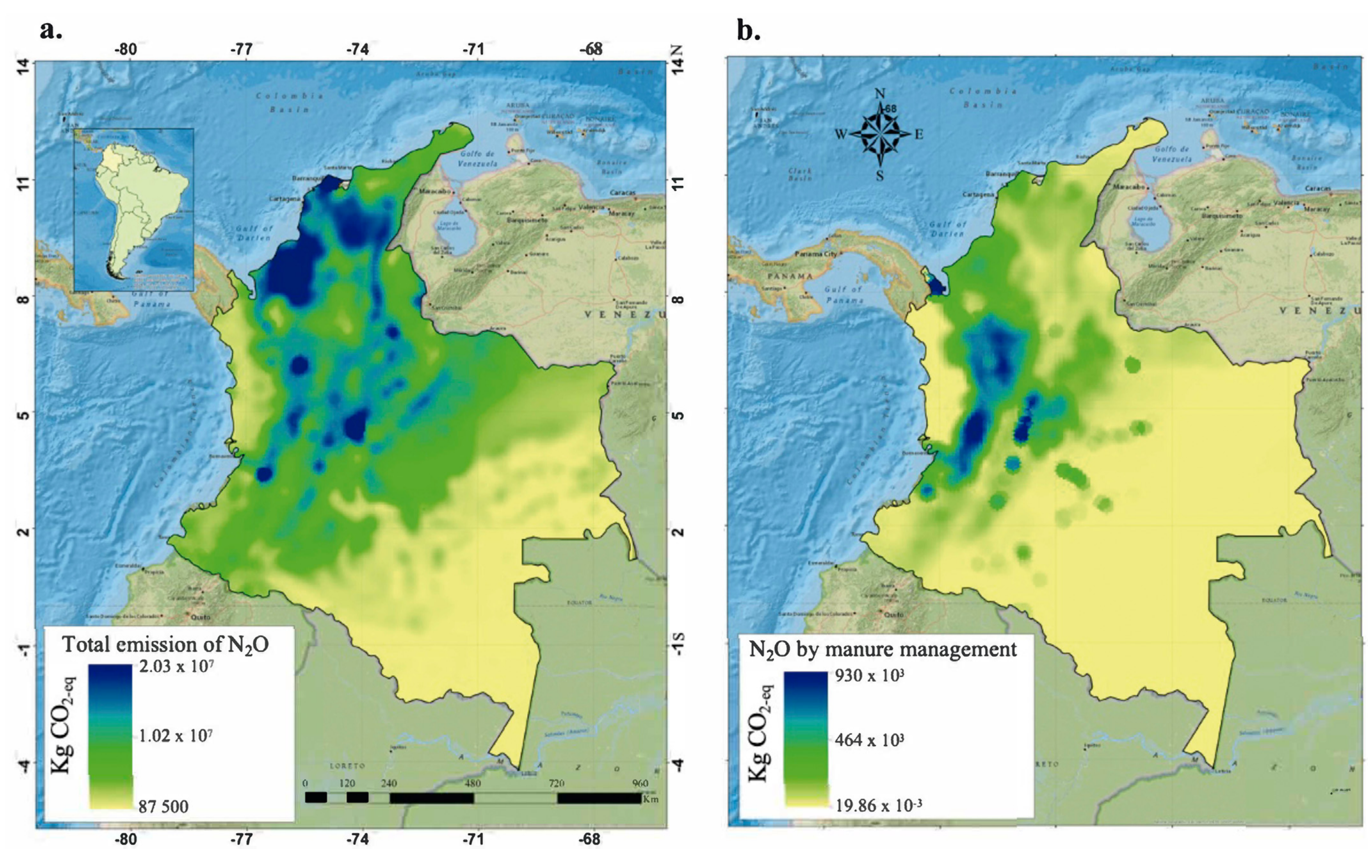

Figure 3. (a) N_2O Emissions in 2015. (b) N_2O Emissions from Manure Management in 2015.

sectors (classified according to the IPCC), show that enteric fermentation is responsible for the highest methane emissions in the country over time (Figure 4c).

3.2. Statistical results

The correlation test shows all case has direct emission between the emission of CH_4 (Enteric fermentation and manure management) with all age of bovine inventory, while the N_2O emission shows an indirect relation with all age of bovine inventory, except with group $1 \geq 2$ years (Table 2). However, in all cases, the coefficient is less than 0.7 (Table 2). Now, when applying a post hoc test of the Kruskal-Wallis test, the results allow inferred that the age of bovine has a strong influence on the emission of CH_4 and N_2O. Although, the latter GHG does not seem influence by bovines older than 2 years (Table 2).

4. Discussion

According to Figure 1, there is a marked decrease in emissions from 2011 to 2013 and an increase from 2013 to 2014, which coincides with indications by the FEDEGAN and the National Livestock Fund. The reduction in livestock production in 2010–2012 occurred due to El Niño and La Niña phenomena, which caused deaths and reproductive damage. Similarly, there was an increase of approximately 1% from 2013 to 2014 (FEDEGAN, 2019).

Concerning the emission values obtained in 2015, values proportional to the values of the National Inventory of GHG published by the IDEAM in 2016 are found. The results of CH_4 emissions by enteric fermentation of the IDEAM show for the year 2012 values of 20.7×10^9 kg of CO_2-eq and of 2.4×10^9 kg of CO_2-eq for emissions of CH_4 and N_2O by manure management, which suggests similar trends in the values obtained in the study (IDEAM, 2016). However, the differences can be attributed to the accuracy of the sources of data collection for processing emissions and the influence of external factors and variables in the measurements of CH_4 and N_2O emissions.

In Figure 1, the highest values of the emission sources are obtained for CH_4 emissions by enteric fermentation. These proportions correspond to the results published by authors in several countries. Nieto et al. (2014) found in their study that 74% of the emissions correspond to CH_4 emissions by enteric fermentation; additionally, various studies have mentioned a more significant influence of CH_4 emissions by enteric fermentation of food in the digestive tract of cattle (Morales-Velasco et al., 2016; Vac et al., 2013). The high and low spots in Figure 2b, c and Figure 3a, b is according to the distribution of cattle of the National Agricultural Survey (DANE, 2021). The behavior of N_2O emissions in the northern zone may also be due to dual-purpose livestock activity in the region and to the volatilization of N (Rosa et al., 2022). CH_4 emissions result from the amount of CH_4 excreted by cattle and depend on the diet, digestive system of the ruminant, quality, and digestibility of specific components of the diet, and protein concentration and energy in the rations (Murgueitio et al., 2014; González et al., 2015; Costantini et al., 2018). This is why the post-doc of the Kruskal-Wallis test shows that age influences CH_4 emission. Likewise, Studies show that the inclusion of grains in a ruminant diet decreases the acetic acid production in the rumen, and a decrease in the amounts of CH_4 emitted is achieved (Parra-Cortés et al., 2020).

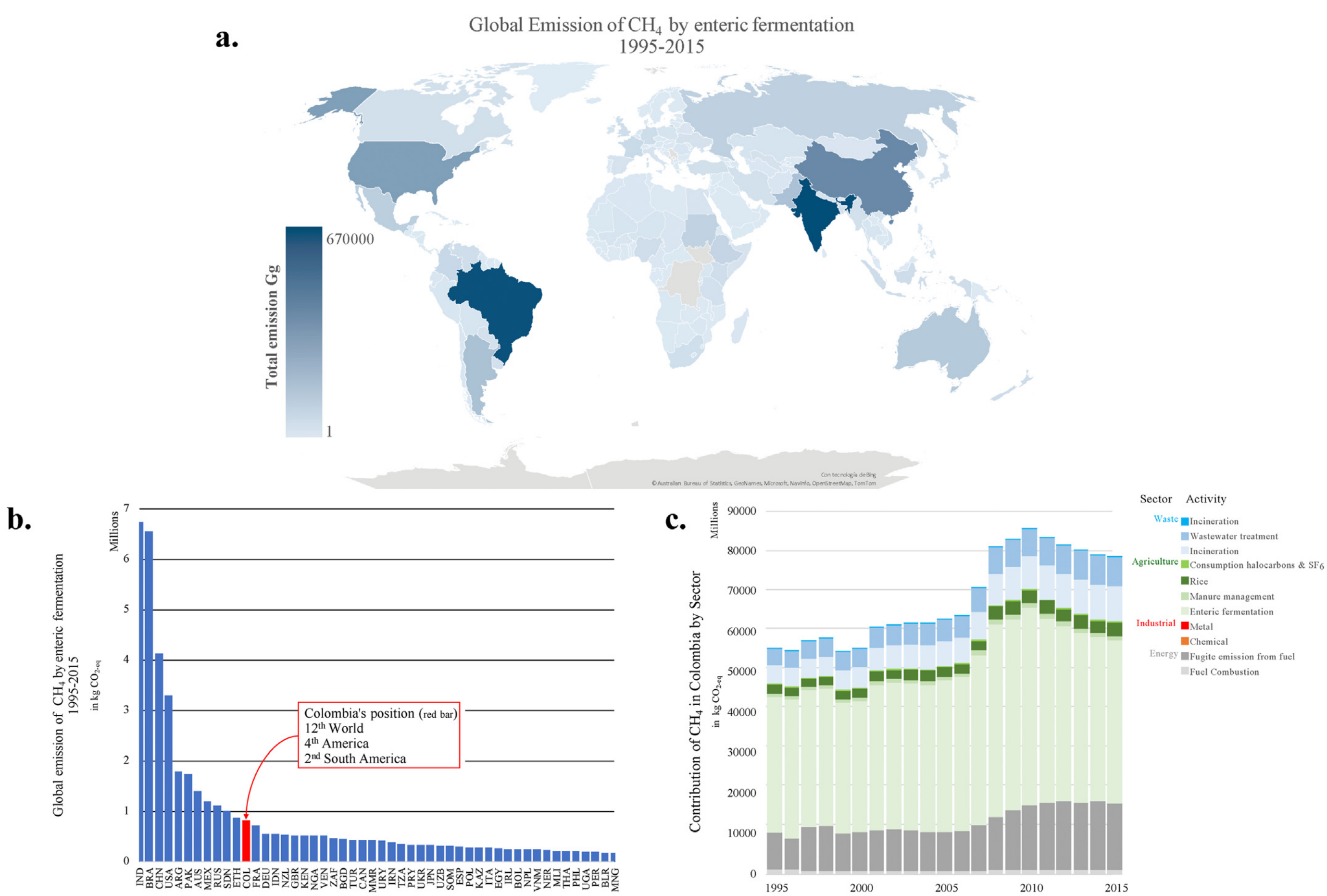

Figure 4. (a) Comparative results of emission of CH_4 by enteric fermentation during 1995–2015. A. Global-scale maps estimation, (b) value of the first 50 countries with the highest emissions (c) historical records of CH_4 for different sectors under IPCC classification in Colombia.

Table 2. Statistical results of GHG emission and national livestock survey.

Bovine inventory variable		GHG emission variable		
		CH_4	N_2O	
		Enteric Fermentation*	Manure Management	
Group 1 BI	<1 year	●	●	●
		96.8	**76.8**	**56.8**
	1–2 years	●	●	●
		82.8	**62.8**	**42.8**
	>2 years	•	•	•
		60.4	**40.4**	20.4
Group 2 BI	<1 year	●	•	•
		49.8	**39.8**	**29.8**
	1–2 years	●	•	•
		40.2	**30.2**	20.2
	2–3 years	●	●	•
		47.0	**37.0**	27.0
	>3 years	●	•	•
		36.4	26.4	16.4

* Variable with normal distribution. The number is the difference observed between variables, and blond letter means significance with a level of 95%. Blue is a direct correlation. Red an indirect correlation. Scale of Spearman correlation value: ● ≥ 0.7, ● 0–7–0.5, ● 0.5–0.3, ● 0.2–0.1, • ≤0.1.

Using images to represent emissions of CH_4 and N_2O in Colombia from database information may present variations in the data. According to the literature, the variations are mainly attributed to the occurrence of phenomena such as El Niño and La Niña and the intervention of variables such as precipitation (Parker et al., 2018), and in the case of the use of satellite images, variables such as cloud cover, during the imaging (Tello et al., 2020).

The results of the statistical tests allow the influence of the sources on the emissions of CH_4 and N_2O to be determined. The post hoc analysis shows that CH_4 emissions from enteric fermentation and manure management have a greater influence than other activities that emit GHG. This result coincides with the results published by Silva et al. (2013) and Morales-Velasco et al. (2016), who indicate enteric fermentation and manure management as the main sources of CH_4, and by Carro et al. (2018), who suggest that 67.2% of CH_4 of livestock origin is from enteric fermentation and 32% is from manure fermentation. On the other hand, the positive correlation between CH_4 emissions by enteric fermentation and manure management with the age groups of cattle suggests that the increase in CH_4 emissions is associated with livestock production for the age groups analyzed.

Finally, it is important to list below the main limitations in the development of this study: (i) the availability of records in the EDGAR database about GHG, which were available up to 2015 for Colombia; (ii) the access to information from the livestock census is laborious, and its organization made complex the analysis for the purposes of this study. On the other hands, the results have allowed us to identify opportunities for work on the impact of GHG emissions associated with livestock activity and future scenarios.

5. Conclusions

The results of GHG emissions obtained from the EDGAR v5.0 database during 1995–2015 showed generally higher values during 2010 and 2015 for CH_4 emissions by enteric fermentation and CH_4 emissions by manure management. N_2O emissions showed an increase over time, with higher values in 2015.

In Colombia, higher emissions of CH_4 gas than N_2O gas were obtained. Considering the origin of CH_4 emissions, the highest emissions were obtained for CH_4 by enteric fermentation. Concerning the spatial distribution of emissions, the regions with the highest CH_4 emissions correspond to the northwestern area of Colombia and some regions of the central area, while low emission values were recorded in the southern area. With respect to N_2O emissions, the highest records occurred in the northwestern part of the country.

Statistically, the application of the Spearman correlation test of CH_4 emissions by enteric fermentation and manure management and the age groups of the bovine inventory for the years 1995–2015 showed a positive correlation. The application of the Kruskal–Wallis test showed statistically significant differences, and the post hoc analysis determined differences for the groups formed by CH_4 emissions by enteric fermentation and manure management and the age groups studied.

The application of procedures for obtaining emissions in Colombia from international databases showed agreement with the results published by other authors and with the records indicated by national authorities.

Declarations

Author contribution statement

Fredy Arid Tovar Bernal: Analyzed and interpreted the data; Wrote the paper.

Angélica Garrido Galindo: Contributed reagents, materials, analysis tools or data; Wrote the paper.

Yiniva Camargo Caicedo: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

José Fontanilla: Performed the experiments; Analyzed and interpreted the data.

Andrés M. Vélez Pereira: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data included in article/supp. material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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