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Assessment of the methane emission for different typologies of fattening swine facilities in the department of Antioquia – Colombia

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Abstract. The explosive growth of swine production at high stocking densities in confinement farming worldwide, has raised concerns the environmental impact, health and livestock productivity and the production of associated gases in this type of large-scale farms. The aim of this paper was to study the methane gas concentration and emissions of ten different typologies of swine production installations. The facilities were in the department of Antioquia - Colombia, they were located between 800–2,300 meters above sea level (m.a.s.l.) of heights, they mainly employed natural ventilation as refrigeration strategy and they were used for pigs in fattening stage. Methane measurements were taken at animal height. Sensors were located at intermediate points of the ventilation inlet and outlet areas. The behaviour of methane concentration and emission of the facilities were analysed along with the correlation and temporal evolution of climatic variables, comfort indices and construction typologies. The information was analysed using *descriptive statistics*, *analysis of variance (ANOVA)* and *principal component analysis (PCA)*. Were found an *average* of CH_4 Emission Rate (ER) per facility (kg year^{-1}) of 607.9, Global Warming Potential (GWP) per facility (kg year^{-1}) of 15,197.42 and significant correlations between ER and cleaning frequency (CF), animal unit (AU), air flow (Q), animal density(AD) and relative humidity (RH) were evidenced. This is the first research reported in Colombia, that will be important to create some governmental policies.

Key words: typologies of construction, methane emissions, natural ventilation, greenhouse gases, swine production.

INTRODUCTION

The agricultural sector is regarded as the highest user and administrator of natural resources, and as such, is considered to have a high impact on the environment due to its capability of reducing greenhouse gasses emissions (GHG) (Lenerts et al., 2019). GHG emissions represent losses of energy, nitrogen and organic matter for the livestock sector. Consequently, there is a strong link between emission intensity and effective use of resources, and most mitigation interventions will lead to improved efficiency in the use of resources throughout the sector's supply chains (Gerber et al., 2013). developing countries still have to take measures to improve the use of natural resources the potential to reduce 70% of GHG (Gitz et al., 2016) . According to the third national statement of climate change of Colombia, activities such as agriculture, forestry and other uses of the land provide an approximate of 43% of the GHG (70 MtCO_2eq), waste 8%, industrial processes and product use 5% and energy 44% (IDEAM, PNUD, MADS, DNP 2015). Livestock production under confinement optimizes the land usage, however, increases the volume of residues (Briukhanov et al., 2017) that are produced and transformed into gases. These gases are grouped according to their importance in climate change and human health (Petersen et al., 2016). According to the Food and Agricultural Organization (FAO) the livestock sector is estimated to provide 6.2 Gt of CO_2 equivalent (CO_2eq) per year, which represents 14.5% of human induced, of the total emissions of the livestock sector. Swine production generates 0.7 Gt of CO_2eq, which sums up to 9% (Gerber et al., 2013). At the livestock sector, the swine production is at the third-place following by beef and dairy products, a trend that follows the European model, where swine production represents 26% of livestock GHG emissions (Noya et al., 2016). There are other authors who affirm that pig production could have a greater contribution of GHG than milk production, as is the case of De Vries & de Boer, (2010) who consider it should be in second place after beef, with an emission rate between 3.9 to 10 kg of CO_2eq per kilogram of animal. Likewise Noya et al. (2017) stated that swine products are second highest GHG generators amongst meat produce. This has become evident by studies on life cycles developed by Reckmann et al. (2013), Noya et al. (2017) and Noya et al. (2016) in which CO_2eq production per kilogram of meat produced in Germany is 3.22, 3.42 and a last rank of 2.30–3.30 kg, respectively. Monogastric animals as poultry and pigs have had a considerable growth in consumption with a 2.8% annual increase (Steinfeld & Gerber 2010), being the highest meat product consumed in European regions (Noya et al., 2016) and overall worldwide with a growth projection reaching 40% (Nations Food and Agriculture - FAO 2011), which represents a big challenge.

According to de Vries & de Boer (2010) monogastric animals have a higher Global Warming Potential- GWP (It is a relative measure of how much heat can be trapped by a given greenhouse gas, compared to a reference gas, usually carbon dioxide), generally determined by N_2O and CH_4 emissions due to manure management. N_2O and CH_4 are important contributors considering their GWP in the lapse of a century is 298 and 25 times, respectively, higher than CO_2 (IPCC. 2007). GHG generation according to the chain of production go as follows: 1) Animal feed production with 48% of emissions, 2) Manure management and storage with 27.4%, most of it as CH_4 (19.2%), 3) Livestock and livestock feed transportation with a moderate contribution of 5.7% and lastly 4) Farming energy consumption with barely 3.5% of the total emissions. (Gerber et al., 2013). For Gert J. M., Bannink, A. & Chadwick, D. (2006), in monogastric animals, such as pigs, the CH_4 is produced mostly in the large intestine, however, the stockpiled manure in underground pits, outdoors and on the shed floors is also relevant source under the following conditions: 1) The temperature and ventilation rate increase the work of methanogenic bacteria which transform acetate, CO_2 and H_2 into methane in a thermophilic environment, 2) Storage time, 3) Optimum pH close to neutral (Philippe et al., 2011), 4) High levels of degradable organic matter, and 5) High amounts of humidity which facilitate methanogenesis in both the liquid and solid phases of manure. Likewise

Philippe & Nicks (2015) provides that emissions of CO_2, CH_4 and N_2O contribute 81, 17 and 2% of the total emissions in housing, representing 3.87, 0.83, 0.17 kg of CO_2eq per carcass, respectively. The value of CH_4 generation in housing by an animal in the fattening stage is 16.7 g CH_4 per day, a period that makes for 70% of the total emissions, while periods of gestation, lactation and weaning contribute approximately 10% of the total emissions.

There are currently regulations for toxic gases such as ammonia, however, it was not possible to find evidence of a regulation that can limit emissions of GHG from animal housings. Additionally, the existing legislation is limited to requesting reports, such is the case of the European Union, where producers are requested to report yearly CH_4 emissions higher than 100,000 kg and Israel when it's higher than 10,000 kg a year (Bjerg et al., 2019). There are few studies worldwide regarding the measurement of CH_4 concentrations in swine population in tropical climates, in which the animal housing works on natural ventilation most of the year. The studies, that have been made to focuses on typologies of construction in slurry pits, as shown in the study of Petersen et al. (2016), where 7 housing types were evaluated in Denmark and where it was discovered that the current estimates of CH_4 emissions from pig and cattle manure management sit at 0.032 and 0.015 kg CH_4, respectively, indicating that liquid manure pits in animal confinements are a significant source. Another frequent analysis is the evaluation of the types of floor in the animal housing and their GHG generation, such is the case in Belgium, where evaluated fattening pigs' production on deep litter system and in the straw-flow system (Philippe et al., 2012). One more study developed in North Carolina by Sharpe et al. (2001) in controlled ventilation farms and liquid manure pits under animal confinements. Their results showed that during the cold winter measurement period, CH_4 fluxes averaged 6.9 g CH_4 animal^{-1} d^{-1} and during summer measurement periods, CH_4 fluxes were much greater and averaged 33 g CH_4 animal^{-1} d^{-1}. Several studies have been carried out for NH_3 emissions in Latin America, in Antioquia, Colombia studies have been made on poultry houses (Osorio-Saraz et al., 2014), while in Brazil the focus has been on swine and fishing facilities (Cecchin et al., 2017). None of these reports were made for CH_4 studies. Within this context, this paper had the goal of studying the concentrations and emissions of CH_4 in fattening pigs' facilities, where is difficult to separate GHG emissions made directly by animals from the ones made by manure. As a result, the emissions of animals and their housing are grouped in one category: Emissions of housing (total emissions from livestock and manure within the facilities) (Sedorovich et al., 2007). This paper is one of the first to make such approach in the country.

MATERIALS AND METHODS

This study was conducted in Antioquia, Colombia, where most of the country´s swine production is made (30.7%), in fattening livestock alone the percentage is 35.5%, which equals about 1,394,769 animals, this according to the last survey made by the National Administrative Department of Statistics (Departamento Administrativo Nacional de Estadística (DANE) 2016). The design of the investigation takes an observational approach, given that no variables were affected on the studied units. We evaluated a total of 10 commercial farms that produce pigs in fattening stage in different towns and altitude variables of Antioquia. All of the typologies of construction observed had natural ventilation and their individual characteristics are represented in Table 1.

Table 1. Characteristics of each typology

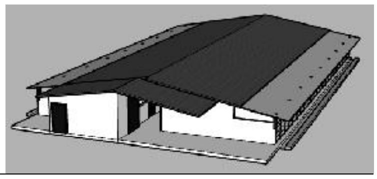
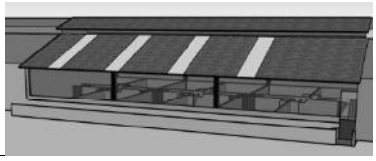
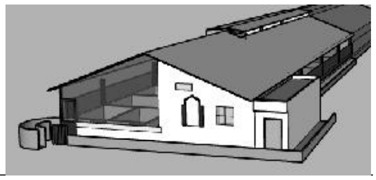
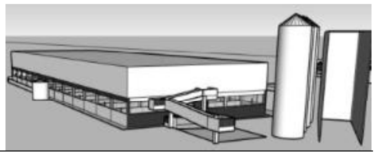
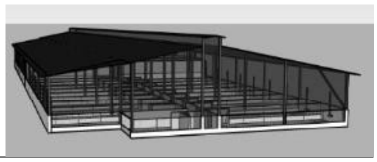
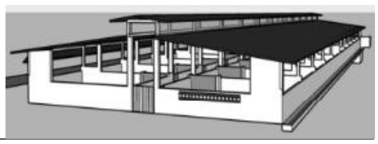
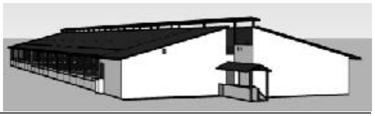
Typology 1	Climate classification: Cold Height above sea level: 2,174 m Temperature: 21.2 °C Relative Humidity: 76% Animal Units: 18.7 Cleaning Frequency: 0	
Typology 2	Climate classification: Mild Height above sea level: 1,179 m Temperature: 27.8 °C Relative Humidity: 67.8% Animal Units: 31.0 Cleaning Frequency: 1	
Typology 3	Climate classification: Mild Height above sea level: 1,481 m Temperature: 25.9 °C Relative Humidity: 65.8% Animal Units: 30.2 Cleaning Frequency: 1	
Typology 4	Climate classification: Cold Height above sea level: 2,202 m Temperature: 22.7 °C Relative Humidity: 64.4% Animal Units: 23.9 Cleaning Frequency: 2	
Typology 5	Climate classification: Mild Height above sea level: 1,504 m Temperature: 26.0 °C Relative Humidity: 63.0% Animal Units: 137.8 Cleaning Frequency: 2	
Typology 6	Climate classification: Warm Height above sea level: 816 m Temperature: 29.1°C Relative Humidity: 62.2% Animal Units: 66.5 Cleaning Frequency: 2	
Typology 7	Climate classification: Mild Height above sea level: 1,732 m Temperature: 25.0 °C Relative Humidity: 64.3% Animal Units: 73.8 Cleaning Frequency: 2	

Table 1 (continued)

Typology 8	Climate classification: Cold Height above sea level: 2,236 m Temperature: 21.8 °C Relative Humidity: 66.7% Animal Units: 72.1 Cleaning Frequency: 1	
Typology 9	Climate classification: Mild Height above sea level: 1,408 m Temperature: 26.2 °C Relative Humidity: 62.2% Animal Units: 49.5 Cleaning Frequency: 1	
Typology 10	Climate classification: Mild Height above sea level: 1,112 m Temperature: 28.4 °C Relative Humidity: 60.6% Animal Units: 164.9 Cleaning Frequency: 2	

* Cleaning Frequency = 0) When the floor is completely evacuated, 1) Daily and 2) Every two days.

Climate description:

Given the varied topography of Antioquia, most of the climate variants are represented, the observed farms were located between 800 and 2,300 meters above sea level, which in turn offers thermal samples of cold, mild and warm climates according to the climate classification from Caldas-Lang. Table 1 shows details of the location of each typology.

Technical Management of the farms:

The research objects correspond to commercial farms of pig fattening, animals were a cross between Landrace and Yorkshire breeds, genetically known as F1 (First generation of a cross of pure breeds). All the observed farms had the same nutritional management of balanced feed made of: 1) Energy sources such as corn, oils, fats and agricultural subproducts, 2) Proteins of vegetal origins, which includes mostly soy and animal flour made of fish, meat, bones and dairy derivatives, and 3) Vitamin and mineral supplements.

Characteristics of the Facilities

Ventilation of these installations is natural procured through windows. procured through windows. In cool weathers lateral curtains were employed, while in mild and warmer conditions half-wall and wall less structures were employed respectively.

Additionally, Seven Typologies presented over roof, all floors were made of smooth concrete in each facility. In Table 1 are presented the average values of some variables and the characteristics of each typology.

Table 2. Typology classification according to Climate classification

Climate classification (masl)	Typology
Warm (0–1,000)	6
Mild (1,000–2,000)	2, 3, 5, 7, 9, 10
Cold (2,000–3,000)	1, 4, 8

The different typologies were classified by thermal variations as shown in Table 2, where most of the farms were located in mild climates, which concurs with the reality of swine production in Colombia.

Timeframe for measurements

The fieldwork for this paper was conducted during the months of May, June and July of 2019. It was reported that the first trimester in which April-May had abundant and frequent rains, with a value higher than 300 millimeters, this according to the information provided by the Institute of Hydrology, Meteorology and Environmental Studies (Instituto de Hidrología, Metereología y Estudios Ambientales – IDEAM) and the agriculture ministry of Colombia (Ministerio de Agricultura y Desarrollo Rural (MADR) 2019).

Features of equipment used

A custom-made low cost CH_4-gas measurement system (MGMS) was developed for monitoring purposes. Employing the sensors detailed in Table 3, an Adruino based gas monitoring system was implemented, as can be seen in Fig. 1. Metal oxide semiconductor sensors were employed for measuring CH_4, along with air temperature, relative humidity, atmospheric pressure and air velocity. Data was saved every 5 minutes in a micro SD memory card by the date and time. Also were employed: Bidirectional Anenometer (range 0–60 m s^{-1}, accuracy ± 2%), used to estimate the prevailing wind direction) and an instrument for the analysis of the WetBulb Globe Temperature (**WBGT**) Index (HD 32.2) (working temperature -5 to 50 °C, storage temperature -25 to 65 °C, working relative humidity 0–90% RH no condensation; instrument uncertainty ± 1%).

Table 3. Reference, range and accuracy of low-cost (*LC*) sensors

Sensor	Reference	Range
Air temperature	*SHT31*	-40 to 90 °C
Relative humidity	*SHT31*	0 to 100%;
Air velocity	*Wind sensor Rev P*	0 to 67 m s^{-1}
CH_4 gas	*MQ4*	300 to 10,000 ppm
Pressure	*BMP280*	300–1,100 hPa

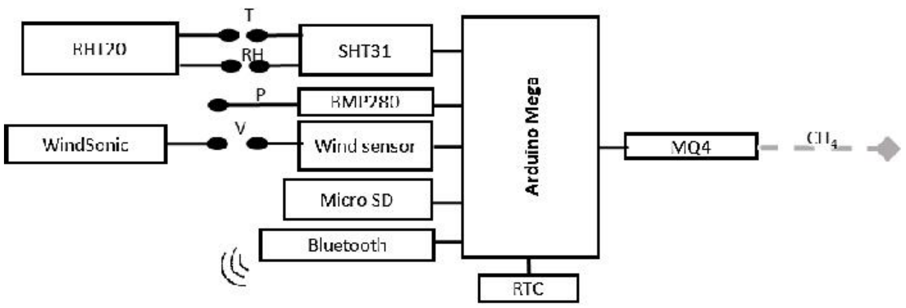


Figure 1. Sketch of the measured variables setup: stand-alone sensors. Measured variables: temperature (T), relative humidity (RH), air velocity (V) and atmospheric pressure (P) and methane (CH_4).

Location of the collector devices and measurement frequency

The research object was the animal housing. The data collection was made continuously during 24 hours in each farm. 4 sensor kits were installed in the middle of the ventilation area, to determine predominant direction of winds, inlets and outlets of air flow. The location for each of the sensor boxes was altered according to each of the typologies of construction evaluated.

Emission factors determination and other variables

The monitored variables using the sensor systems were:

- Temperature (T) = °C;
- Relative humidity (RH) = %;
- Atmospheric pressure (P) = mbar;
- Air velocity (V) = $m^{-1}h$;
- Black globe temperature (Tg)= °C;
- Dew point temperature (Dp) = °C;
- Sensor box area for air flow (BA) = 0.00456 m^2.

The relevant variables of each typology of construction were:

- Height above sea level (hasl);
- climate classification (CC) = Caldas -Lang methodology;
- average animals' weight (AW) = kg;
- Total amount of animals at the facility (AA);
- Total facility area (A) = m^2;
- Effective ventilation area (EVA)= m^2;
- Cleaning frequency (CF) = 0 when the facility is completely evacuated, 1 daily and 2 every two days.

The calculations made to find the variables to analyse were:

a) Animal unit (**AU**): The emissions in the housing facilities are represented as kg AU^{-1}, in which one AU is represented in 500 kg of animal mass.

b) animal density (**AD**) equation:

$$AD = (AW * AA)/A \tag{1}$$

*Expressed in m^2.

c) Ventilation airflow rate (**Q**) equation:

$$Q = V * BA \tag{2}$$

*Expressed in m^3h^{-1}.

d) Factor **K** to converter concentration CH_4 ppm in kg m^3 in function of the following variables: P = Pressure; n = Moles of gas; T = Temperature; R = Universal constant of ideal gases.

e) Concentration of CH_4 (**C**) =

$$C = C_0 - C_i \tag{3}$$

were C_0 = outlet gas concentration, ppm; C_i = inlet gas concentration, ppm; *Expressed in ppm.

f) Emission Rate (ER) equation:

$$ER = KQ(C_0 - C_I) \quad (4)$$

were C_0 = outlet gas concentration, ppm; C_i = inlet gas concentration, ppm; *Expressed in ppm; *Expressed in kg year^{-1}.

g) **THI Index** temperature humidity index (Machado et al., 2016):

$$THI = (0.8 * T) + RH \left[\frac{T - 14.3}{100}\right] + 46.3 \quad (5)$$

were T = air temperature (°C); RH = relative humidity (%).

h) **WBGT index** wet bulb and black globe temperature index (de Oliveira Júnior et al., 2018):

$$WBGT = 0.7\ \text{wbT} + 0.2\ \text{Tg} + 0.1\ \text{dbT} \quad (6)$$

were wbT = wet-bulb temperature; Tg = black globe temperature and dbT = dry bulb temperature.

i) Global Warming Potential (GWP) equation:

$$ECO_2eq = 25\ ECH_4 \quad (7)$$

* Expressed in kg year^{-1} per farm; * taking into account that the warming potential of CH_4 over a100-year period are 25 times that of CO_2 (Salomon et al., 2007). This estimation considered the emissions from the building.

Statistical design

To process the information, the *Principal Components Analysis (PCA)* method was used to obtain an efficient model for emission rates. A model of 12 characterization variables was obtained from the typologies. Additionally, the calculations were developed correlating the variables of emission rates. Descriptive statistical tools were used alongside *analysis of variance (ANOVA)*. All of the calculations were developed in the R Software (RStudio: Integrated Development for R. RStudio, Inc., Boston, MA).

RESULTS AND DISCUSSION

The average values, confidence intervals and standard deviation for the studied typologies are presented in Table 4, where shows the ER (kg year^{-1}) average of 607.90 ± 588.13, THI 74.95 ± 4.67 and WBGT 73.21 ± 4.95. Table 5 and 6 shows the Emission Rates (ER) and the GWP by typologies of construction. According to the meta-analysis developed by Philippe et al. (2013), CH_4 ER in pig production is in the range of 5 to 60 g day^{-1} animal^{-1}, additionally a study developed in breeding farms with deep litter system and controlled ventilation reports emission values between 9.9 to 12.8 g day^{-1} animal^{-1} (Philippe et al., 2013). Another study developed under the same typological characteristics, but in the fattening period by Philippe et al. (2012) found ranges between 7.2 to 25.1 g d^{-1} animal^{-1}. At the present study, values between 1.22 to 20.98 g day^{-1} animal^{-1} (Table 6) were obtained, which are in the range of those found in other studies. However, the average that was found (6.14 g day^{-1} animal^{-1}) is below than the others studies. The difference can be attributed to the fact that the studied farms have natural ventilation and the average values with which they are being compared come from farms with other refrigeration systems and typology of construction. In addition, it is important to highlight that the floors of the evaluated farms corresponded to concrete floors to which a dry removal of the excrement or frequent washing is normally carried out. Therefore, less fermentation processes should be expected and as a consequence lower CH_4 emissions.

Table 4. Average values, confidence intervals and standard deviation of each variable

	Mean	*confidence intervals*		*std*
ER (kg year^{-1})	607.90	440.75	775.04	± 588.13
EVA(m^2)	157.55	128.88	186.21	± 100.88
P(mbar)	854.81	839.62	870.00	± 53.45
THI	74.95	73.62	76.28	± 4.67
WBGT(°C)	73.21	71.80	74.61	± 4.95
T (°C)	25.43	24.26	26.59	± 4.10
CF	1.50	1.31	1.69	± 0.68
AU	66.85	53.45	80.26	± 47.17
Q	6.88	5.69	8.07	± 4.20
AD	55.46	50.58	60.34	± 17.17
Hals (masl)	1.584.40	1449.70	1719.10	± 473.98
RH (%)	64.99	62.66	67.31	± 8.18

Table 5 shows CH_4 ER by typologies of construction. It was found that the emissions rate (ER) of typology 1 has a significant difference due to the low values that could be related to the low average temperature (21.24 °C), high average relative humidity (76%) and the low density of animals (27 kg m^{-2}). Typology 5 is highlighted with a significant difference between the high emission values of CH_4 respect to the average, both typologies show significant differences in the result of the mean value of ER in relation to the others. The typologies that presented greater ER AU are 2 and 4 (Table 6) which are located in cold and mild climates, this high emission could be explained in part by the area of natural ventilation (96 and 24.8 m^2) smaller compared to the average typologies as show in Table 4 (*mean* 157.5 m^2), animals density (70.5–76.3 kg m^{-2}) above average (55.46 kg m^{-2}), and animals mass (90–110 kg) above the average (83.3 kg). Typology 1 (Table 6) exhibit value for ER AU year^{-1} (2.77 kg year^{-1}) below the average (12.5 kg year^{-1}), which could be due to a low density of animals (27.86 kg m^{-2}). Among the other typologies there were no significant differences. A study developed in North Carolina by Sharpe et al. (2001) shows CH_4 fluxes averaged 6.9 g CH_4 animal^{-1} d^{-1} in winter, results close to the average presented in this study (6.14 g day^{-1} animal^{-1}).

Table 5. CH_4 ER by typologies of construction multiple comparison test

Typology	ER facility (kg year^{-1})	*std*	*Group
1	51.90	± 48.00	*b*
2	947.26	± 531.01	*ab*
3	217.24	± 127.24	*ab*
4	1,018.29	± 808.57	*ab*
5	1301.98	± 916.15	*a*
6	315.21	± 410.72	*ab*
7	354.65	± 298.39	*ab*
8	563.48	± 361.83	*ab*
9	507.75	± 436.70	*ab*
10	801.20	± 285.28	*ab*
Mean	607.90		

* Results of Tukey's multiple comparison test.

GWPs are used as a relative index to standardize emissions of GHGs for comparing how efficiently each gas traps heat in the atmosphere (Sedorovich et al., 2007). The index attempts to integrate the overall climate impacts of a specific action, it relates the impact of emissions of a gas to an equivalent emission of a CO_2 mass. The average found of GWP AU among the 10 typologies presented a value of 312.39 kg year^{-1} of CO_2 eq in a GWP time horizon of 100 years (Table 6). It was not possible to find estimated GWP values in swine per facility at literature review, nevertheless, to have an estimate of the magnitude, the facilities emission results of a study in a dairy farm Sedorovich et al. (2007) found average values of GWP AU 1,242 kg year^{-1} CO_2 eq, ratify the lower GWP of pig production, where these results validate those described by Noya et al., (2016) and Vries & de Boer, (2010) who determined that CH_4 emissions in pigs are below cattle. GWP data can be compared with those presented by a review research papers where the median of emission factors for dairy cows (302.5 g day^{-1}·LU-^{1}) was more than three times higher than the value for pigs (85 g day^{-1}·LU^{-1}) (Rzeźnik & Mielcarek 2016).

Table 6. ER per animal, animal unit (AU) and GWP AU

Typology	ER animal (kg year^{-1} animal^{-1})	ER animal (g day^{-1} animal^{-1})	ER AU (kg year^{-1})	GWP AU (kg year^{-1})
1	0.44	1.22	2.77	69.31
2	6.72	18.41	30.54	763.43
3	0.86	2.36	7.18	179.60
4	7.66	20.98	42.54	1,063.38
5	2.17	5.96	9.45	236.26
6	0.66	1.82	4.74	118.50
7	1.10	3.03	4.80	120.09
8	1.09	3.00	7.82	195.38
9	0.92	2.53	10.26	256.44
10	0.76	2.08	4.86	121.47
Mean	2.24	6.14	12.50	312.39

Table 7. Anova and Tukey's multiple comparison test Concentrations of CH_4 (ppm) and thermal comfort indices for each typology

Typology	C (ppm)	*std*		WBGT	*std*		THI	*std*	*Group
1	103.6	± 66.58	*b*	69.4	± 1.81	*a*	72.4	± 2.50	*ab*
2	704.4	± 391.26	*a*	73.4	± 2.88	*a*	76.6	± 3.20	*ab*
3	63.8	± 33.27	*b*	72.4	± 3.04	*a*	73.2	± 2.28	*ab*
4	266.4	± 130.10	*ab*	68.8	± 2.28	*a*	68.6	± 3.43	*b*
5	267.4	± 215.40	*ab*	73.4	± 2.79	*a*	76.0	± 3.24	*ab*
6	66.2	± 64.01	*b*	77.6	± 3.50	*a*	79.2	± 2.48	*a*
7	161.4	± 131.26	*b*	75.4	± 6.46	*a*	75.4	± 5.72	*ab*
8	179.6	± 129.39	*b*	69.0	± 2.91	*a*	72.2	± 2.94	*ab*
9	105.2	± 78.8	*b*	74.8	± 6.22	*a*	76.6	± 5.41	*ab*
10	184.6	± 57.2	*b*	78.0	± 5.43	*a*	79.2	± 4.54	*a*

* Results of Tukey's multiple comparison test.

To evaluate the relationship of thermal comfort indices with CH_4 gas, was used the concentration variable (C) obtained with equation 4 described in materials and methods, the results can be seen in Table 7 as well as those of THI and WBGT indices. Among the typologies 1, 3, 6, 7, 8, 9 and 10 there were no significant differences, among the 1, 3 and 6 were the lowest concentrations. The highest concentration occurred in facility 2, followed by 4 and 5, located in cold and mild climates. Typology 2 presented very high concentration values of CH_4 (C) respect to the mean and median; which could be explained by the adverse positions in most of the measured variables; high temperatures T (27.8 °C), high animal density AD (70.5 kg m^{-2}), cleaning frequency (CF) of 2 days and one of the lowest air velocity (V) (0.17 m s^{-1}). In the same way values of THI and WBGT reached are shown in Table 7. It can be seen that the typological facilities 1, 3, 4 and 8 were below THI $\leq$ 74, which suggests that the farms are most of the day in a situation of thermal comfort, similar results with those of the WBGT index with values under 72. Facilities that present an environment of greater thermal discomfort are Typologies 2, 5, 6, 7, 9 and 10, having a greater relationship with ventilation type than for its location at height above sea level. The highest values of WBGT and THI were found in typologies 6, 7 and 10, which are located in mild and warm climates mainly.

Fig. 2 and Table 8 presents the results of a Principal Component Analysis *(PCA)*, developed to find correlations between ER and the other measured variables. There are records that production levels of CH_4, can be altered by several factors, such as housing conditions, manure management and diet composition (Philippe & Nicks, 2015). This study can support these alterations with the findings of significant correlations between ER y CF, AU, Q, AD y RH, results are presented in Table 8.

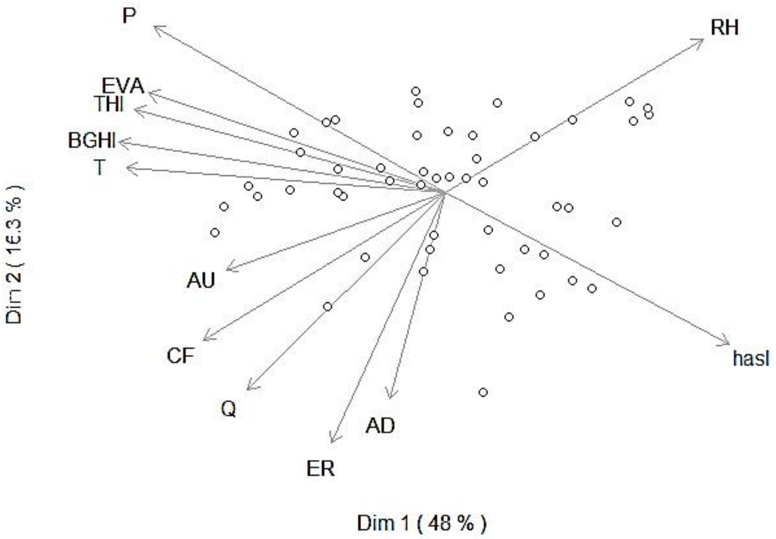


Figure 2. *Principal Component Analysis (PCA)*

According to Gabriel et al. (2014) and Petersen et al. (2016) there is evidence that the ER CH_4 emitted from stored slurry declines with decreasing temperature, as also was found by Sharpe et al. (2001) their results showed that during the cold winter measurement period, CH_4 fluxes averaged 6.9 g CH_4 animal^{-1} d^{-1}

Table 8. Variables with *significant correlations* with ER

	correlations	*pvalue*	*confidence intervals*	
CF	0.309	0.029	0.034	0.541
AU	0.292	0.040	0.015	0.527
Q	0.463	0.001	0.212	0.657
AD	0.279	0.050	0.001	0.517
RH	-0.372	0.008	-0.589	-0.105

and during summer measurement periods, CH_4 fluxes were much greater and averaged 33 g CH_4 animal^{-1} d^{-1}. However, it was not possible to find in this study a direct relationship between T and ER. Although Fig. 2 does not indicate a direct relationship between the height above sea level (hals) and ER, it was found that typologies 6 and 10 located in warm weather, as well as typologies 7 and 9 located in temperate climates also have high indices of thermal discomfort, as shown in Table 7.

CONCLUSIONS

This study represents a Colombia first approach to estimate emission factors (ER) of CH_4 of the housing in fattening pigs' facilities. The results obtained from this study are added to others developed in different countries that have shown evidence that the emissions generated in the facilities are important and should be incorporated into national greenhouse gas inventories, with an average CH_4 Emission Rate (ER) per facility of 607.9 kg year^{-1}. Even though the data gathered in this work exhibit high variability, due to the climatic and typology of construction diversity, they can be used to guide further research. The present research highlights that the estimation of ER is a multivariable problem, where the correlations between, environmental, physiological, structural and animal management variables must be considered. It is shown that at different typologies of construction used in Colombia that operate with natural ventilation, significant levels of ER are presented, finding a higher ER in cold and mild climates where 80% of Antioquia state pig farming is concentrated, That could be, due to typologies in the cold and mild climates facilities have less natural ventilation than the warm climate. However, it is necessary to go deeper into this type of study, especially in typologies located in warmer weathers. In addition, it shows how these typologies in summer months, which are the majority of the year in tropical countries, it should use systems that improve animal thermal comfort, because they have adverse conditions according to the THI and WBGT indexes founded.

It is hoped that this work will serve as a basis for advancing a national inventory of gas emissions in the pig sector and guiding policies and strategies to minimize the impact that the swine sector can produce on the environment in the country.

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