



Assessment of the Contribution of Poultry and Pig Production to Greenhouse Gas Emissions in South Korea Over the Last 10 Years (2005 through 2014)

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ABSTRACT: The goal of this study was to estimate the emissions of greenhouse gases (GHG), namely methane (CH₄), nitrous oxide (N₂O), and carbon dioxide (CO₂) from poultry and pig production in South Korea over the last 10 years (2005 through 2014). The calculations of GHG emissions were based on Intergovernmental Panel on Climate Change (IPCC) guidelines. Over the study period, the CH₄ emission from manure management decreased in layer chickens, nursery to finishing pigs and gestating to lactating sows, but there was a gradual increase in CH₄ emission from broiler chickens and male breeding pigs. Both sows and nursery to finishing pigs were associated with greater emissions from enteric fermentation than the boars, especially in 2009. Layer chickens produced lower direct and indirect N₂O emissions from 2009 to 2014, whereas the average direct and indirect N₂O emissions from manure management for broiler chickens were 12.48 and 4.93 Gg CO₂-eq/yr, respectively. Annual direct and indirect N₂O emissions for broiler chickens tended to decrease in 2014. Average CO₂ emission from direct on-farm energy uses for broiler and layer chickens were 46.62 and 136.56 Gg CO₂-eq/yr, respectively. For pig sectors, the N₂O emission from direct and indirect sources gradually increased, but they decreased for breeding pigs. Carbon dioxide emission from direct on-farm energy uses reached a maximum of 53.93 Gg CO₂-eq/yr in 2009, but this total gradually declined in 2010 and 2011. For boars, the greatest CO₂ emission occurred in 2012 and was 9.44 Gg CO₂-eq/yr. Indirect N₂O emission was the largest component of GHG emissions in broilers. In layer chickens, the largest contributing factor to GHG emissions was CO₂ from direct on-farm energy uses. For pig production, the largest component of GHG emissions was CH₄ from manure management, followed by CO₂ emission from direct on-farm energy use and CH₄ enteric fermentation emission, which accounted for 8.47, 2.85, and 2.82 Gg-CO₂/yr, respectively. The greatest GHG emission intensity occurred in female breeding sows relative to boars. Overall, it is an important issue for the poultry and pig industry of South Korea to reduce GHG emissions with the effective approaches for the sustainability of agricultural practices. (**Key Words:** Greenhouse Gases, Emission Intensity, Pig, Poultry, South Korea)

INTRODUCTION

Livestock production is changing dramatically in response to global population growth and increasing demand for livestock. For instance, the global demand for pig meat, chicken meat and chicken eggs is forecast to grow by 32%, 61%, and 39%, respectively, between 2005 and

2030 (Gerber et al., 2013). However, many studies have warned that increasing livestock production could cause environmental problems, particularly exacerbating global warming (Lee and Lee, 2003; Ji and Park, 2012; Caro et al., 2014). A recent report from the United Nations Food and Agriculture Organization detailed the global environmental problems of the livestock industry (Steinfeld et al., 2006). In the section “*Livestock’s long shadow: environmental issues and options*”, the report states that livestock production is one of the most important contributors to the emission of greenhouse gases (GHG), namely methane (CH₄), carbon dioxide (CO₂) and nitrous oxide (N₂O).

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Livestock production contributes approximately 80% of global anthropogenic GHG emissions (Gerber et al., 2013). Many studies have drawn attention to GHG emissions from ruminants due to enteric fermentation in the rumen, including manure management. However, few studies have examined GHG emissions in pig and poultry sectors. According to the Gerber et al. (2013), the global pig and poultry supply chains contribute GHG emissions of 0.7 and 0.6 Gg CO₂-eq/yr, representing nine and eight percent of the livestock sector emissions, respectively.

According to Korean Statistical Information Service estimates, in 2014, South Korea had 8 to 10 million pigs and 72 million head of broiler chickens (KOSIS, 2015). This expanding population will be a challenge for the livestock industry. However, there is limited data for GHG emissions from livestock agriculture over the past decade (Lee and Lee, 2003; Nam et al., 2008; Lim et al., 2011). Previous reports have emphasized quantifying CH₄ emissions during enteric fermentation for a national inventory, manure treatment facilities (Lim et al., 2011), livestock manure and waste co-digesting biogas (Nam et al., 2008). Recently, Won et al. (2014) found that CH₄ and N₂O emissions from sows, layer chickens and Korean cattle were very different, and an increased C/N ratio was associated with higher CH₄ emissions, which were lower than the proposed values from the Intergovernmental Panel on Climate Change (IPCC, 2006). However, few studies have estimated GHG emissions according to the IPCC guidelines in South Korea. One example is a report by Ji and Park (2012), who found that the annual growth rates of enteric CH₄ emission, CH₄ and N₂O emissions from manure management from 1990 to 2009 were 1.7%, 2.6%, and 3.2%, respectively. Thus, there is a major knowledge gap in understanding the GHG emissions from livestock and poultry production. The goal of the current study was to quantify the emissions of GHG associated with monogastric livestock production (pigs, broilers, and laying hens) in South Korea over last 10 years (2005 through 2014) by following the IPCC guidelines.

MATERIALS AND METHODS

Livestock population

Livestock population data were obtained from the Korean Statistical Information Service for each year from 2005 to 2014 to estimate the emissions of CH₄, CO₂ and N₂O from pig and poultry farming (KOSIS, 2015). The pigs were divided into three categories (nursery to finishing pigs, gestating to lactating sows and boars) and the chickens were divided into two categories (broilers and layers).

Method tiers

The GHG emissions were estimated at different levels of complexity (Table 1). Our GHG calculations followed the IPCC methodology (IPCC, 2006).

Enteric fermentation emissions

Enteric fermentation emissions in the large intestine can produce CH₄ as a by-product of digestion. Methane production from microbial fermentation of feed in the gastrointestinal tract was calculated using the Tier 1 method from the IPCC (2006) guidelines for each category. We estimated the default emission factor base from the IPCC guidelines for the recommended population subgroup (i.e., annual CH₄ emission per animal). The emission factors were multiplied by the animal population in each category and summed over the entire country in each year (Gerber et al., 2013).

Methane emission from manure management

Manure production from feces and urine during pig production are considered to be excreta production. The IPCC (2006) default CH₄ emission factors for pig manure management, combined with the annual average temperature of South Korea, were used to estimate CH₄ emission from manure management in each subcategory. Total CH₄ emission from manure management was estimated by multiplying the emission factor (EF = 2 kg CH₄/head/yr) for Asia; IPCC (2006) in manure management

Table 1. The methods for estimation of greenhouse gases emissions, emission categories, equations, and emission factors

Gas	Emission category	Required data	Equations ¹	Emission factors
CH ₄	Enteric fermentation	Stock (head)	10.19 10.20	Table 10.10
	Manure management	Stock (head)	10.22	Table 10.14
N ₂ O	Manure management direct	Manure N	10.25	Table 10.21 Table 10A-7
	Manure management indirect (volatilization)	Manure N	10.26	Table 10.22
			10.27	Table 11.3
			10.30	Table 10.19
CO ₂ ¹	Direct on-farm energy uses	Stock (head)		Table E6

GHG, greenhouse gases.

¹ Equations and emission factors are reported by the corresponding equation and table in chapter 10 and 11 of the IPCC guidelines (IPCC, 2006).

for each subcategory of animals and summed over the entire country. The manure management system for broiler and layer chickens was composting. In this study, the EF was defined as 0.03 for layers and 0.02 for broilers.

Nitrous oxide emissions from manure management

The production of direct N₂O emission from manure was estimated using the Tier 1 method (IPCC, 2006), in which direct N₂O emission depends on the total N excretion in each type of manure management system. The Tier 1 method was used to multiply the total amount of N excretion in each type of manure management system by the EF. Emissions were then summed over all of the manure management systems. The Tier 1 approach was applied using the IPCC's default N₂O emission factors, default N excreta data and default manure management system data (IPCC, 2006).

Indirect N₂O emission from volatile nitrogen losses primarily occurred in the form of ammonia and NO_x. Nitrogen losses begin at the point of excretion in animal production areas and continue through on-site management in storage and treatment systems. The Tier 1 method was used to calculate N volatilization in the form of NH₃ and NO_x from manure management systems based on multiplying the excreted nitrogen in each manure management system by a fraction of volatilized nitrogen (IPCC, 2006). Nitrogen losses are then summed over all of the manure management systems. For poultry, uric acids are rapidly metabolized to ammonia nitrogen, which is highly volatile and easily diffuses into the surrounding air.

Carbon dioxide emissions from direct on-farm energy uses

The calculation of CO₂ emission from direct on-farm energy uses followed the methods in IPCC (IPCC, 2006). The main categories of direct on-farm energy use are ventilation, lighting, heating, feeding, manure handling, washing, and miscellaneous uses (Hörndahl, 2008). We did not consider the energy uses during feed processing and transport because direct on-farm energy use in the industrial system of South Korea was not included in the IPCC methodology (IPCC, 2006). In this study, the average direct energy use was 1.76 MJ/kg live weight for pigs, 1.26 MJ/kg egg for laying hens, and 4.54 MJ/kg carcass weight for broiler chickens (IPCC, 2006). Then, the calculated emissions for average electricity consumption per kg of meat were multiplied by electricity-specific factors. The EF for electricity in South Korea is 0.504377662 kg CO₂/kW h (Brander et al., 2011).

RESULTS AND DISCUSSION

Total greenhouse gas emissions in poultry and pig

industry

The preliminary data of the current research in 16-local districts of pig and poultry production was mainly located in Chungcheongnam-do and Gyeonggi-do, and moderated producing area in Jeollabuk-do, Jeollanam-do, Gyeongsanbuk-do and Gyeongsangnam-do. Yearly emissions of GHG in monogastric animals of South Korea from 2005 to 2014 were evaluated, and data for the 10 years are given in Table 2. Our results demonstrated that CH₄ from manure management has decreased in layer chickens, nursery to finishing pigs, and gestating to lactating sows. However, there was a gradual increase in CH₄ emissions from broiler production and an increase in CH₄ emission for male breeding pigs.

Enteric CH₄ emission was negligible in boars. A yearly increase in CH₄ emission was observed in nursery to finishing pigs, but it was constant for female breeding sows. Enteric CH₄ fermentation emission was highest in 2009 but lowest in 2011 in the two categories of pig production.

Average direct and indirect N₂O emissions from manure management from broiler chickens were 12.48 and 4.93 Gg CO₂-eq/yr, respectively. Annual direct N₂O emission generally decreased from 2009 to 2014, but indirect emission remained stable. For layer chickens, there was a decrease in N₂O emission from 2009 to 2014. Direct and indirect N₂O emissions were 18.28 and 100.53 Gg CO₂-eq/yr, respectively. In nursery to finishing pigs, both categories of N₂O emissions gradually increased, whereas the emissions decreased for breeding pigs.

Average CO₂ emission from direct on-farm energy uses for broiler and layer chickens were 46.62 and 136.56 Gg CO₂-eq/yr, respectively. In 2009, CO₂ emission reached a maximum of 53.93 Gg CO₂-eq/yr, but it declined in 2010 and 2011, and then remained stable in the following two years. For boars, CO₂ emission reached a maximum of 9.44 Gg CO₂-eq/yr in 2012. For gestating to lactating sows, CO₂ emission was highest in 2009, and then gradually declined in the remaining years.

Total CO₂ equivalent greenhouse gases emissions and emission intensity in poultry production

The GHG emissions from poultry production in South Korea are summarized in Table 3. The total GHG emissions from layer chickens were higher than from broiler chickens. For broiler chickens, indirect N₂O emission was the largest component of GHG emissions, followed by CO₂, CH₄, and direct N₂O emissions. However, the largest component of GHG emissions in layers was CO₂ from direct on-farm energy uses, followed by CO₂, indirect N₂O, CH₄, and direct N₂O emissions. Therefore, layer chickens had greater emission intensity than broiler chickens. However, the emission intensity associated with CO₂ emission from direct on-farm energy uses was higher in broilers than in layer

Table 2. Greenhouse gases emissions from poultry and pig production between 2005 and 2014 in South Korea (Gg CO₂-eq/yr)

Greenhouse gas emissions	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Methane										
Layer chickens	44.85	46.01	47.18	49.03	63.37	53.29	64.63	64.82	53.76	56.42
Broiler chickens	32.15	32.66	33.36	31.86	38.00	40.44	40.94	38.98	38.60	41.88
Nursery to finishing pigs	35.54	36.72	38.12	36.76	37.45	39.58	30.25	38.33	41.04	39.95
Gestation to lactation sows	4.31	4.51	3.61	4.20	5.26	4.46	3.70	4.42	4.26	4.22
Boars	0.16	0.14	0.14	0.13	0.13	1.11	0.12	1.11	0.14	0.16
Direct nitrous oxide										
Layer chickens	15.09	15.48	15.87	16.49	21.32	17.92	21.74	21.80	18.08	18.98
Broiler chickens	10.88	11.05	11.29	10.78	12.86	13.69	13.86	13.19	13.06	14.17
Nursery to finishing pigs ¹	1,103.37	1,140.19	1,183.22	1,140.85	1,162.41	1,229.03	939.33	1,189.72	1,273.94	1,240.55
Gestation to lactation sows ¹	134.14	140.21	112.08	130.60	163.42	138.81	115.57	137.29	132.08	131.50
Boars ¹	4.58	4.32	4.50	4.34	4.19	34.56	4.00	34.81	4.51	5.15
Indirect nitrous oxide										
Layer chickens	43.52	44.22	45.16	43.13	51.44	54.75	55.42	52.76	52.26	56.70
Broiler chickens	43.52	44.22	45.16	43.13	51.44	54.75	55.42	52.76	52.26	56.70
Nursery to finishing pigs ²	235.77	243.65	252.82	243.78	248.39	262.65	200.72	254.23	272.23	265.09
Gestation to lactation sows ²	28.67	29.95	23.94	27.91	35.02	29.66	25.30	29.58	28.54	28.32
Boars ²	0.99	0.93	0.95	0.92	0.89	7.38	0.84	7.43	0.95	1.08
Carbon dioxide										
Layer chickens	120.07	123.23	126.33	127.06	141.37	142.08	144.52	143.80	146.02	151.09
Broiler chickens	40.63	41.28	42.16	40.27	48.02	51.11	51.74	49.26	48.79	52.93
Nursery to finishing pigs	233.70	241.53	250.62	241.67	246.21	260.32	198.97	251.97	269.85	262.76
Gestation to lactation sows	44.27	46.28	37.00	43.09	53.93	45.80	38.16	45.31	43.61	43.40
Boars	1.24	1.16	1.21	1.17	1.12	9.38	1.07	9.44	1.22	1.39
Enteric methane fermentation										
Nursery to finishing pigs	11.81	12.23	12.70	12.25	12.48	13.18	10.09	12.78	13.68	13.33
Gestation to lactation sows	1.45	1.51	1.20	1.41	1.76	1.48	1.23	1.47	1.41	1.41
Boars	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.00	0.00

¹ Unit of direct nitrous oxide emissions in pig was kg CO₂-equivalent/yr.

² Unit of indirect nitrous oxide emissions in pig was metric tons CO₂-equivalent/yr.

chickens (Table 3).

Methane emission from manure management was the

Table 3. Average CO₂ equivalent GHG emissions (Gg-CO₂/yr) and emission intensities (kg-CO₂/yr/head) in broilers and layers from 2005 to 2014

Sector	Broiler chickens	Layer chickens
CO₂ equivalent GHG emissions (Gg-CO₂/yr)		
CH ₄ emission	36.89	54.36
Direct N ₂ O emission	12.48	18.28
Indirect N ₂ O emission	49.93	100.53
Carbon dioxide emission	46.62	136.56
Total	145.92	309.69
Emission intensities (kg-CO₂/yr/head)		
CH ₄ emission	0.50	0.75
Direct N ₂ O emission	0.17	0.25
Indirect N ₂ O emission	0.68	1.39
Carbon dioxide emission	0.63	0.18
Total	1.98	2.57

GHG, greenhouse gases.

CO₂ equivalent GHG emission intensities were kg-CO₂/yr-kg-carcass weight and kg-CO₂/yr-kg-eeg, respectively.

largest component of GHG emissions for layer chickens, broiler chickens and nursery to finishing pigs during 2005 to 2014. Direct N₂O emission was higher in pig (particularly during the nursery to finishing to gestating periods) than in poultry, whereas indirect N₂O emission in layers and broilers accounted for 49.94 kg CO₂-equivalent. The CO₂ emission from direct on-farm energy uses was largest from nursery to finishing pigs, which was higher than from layer chickens. In contrast, GHG emissions from boars were negligible from 2005 to 2014 (Figure 1). We also found that CH₄ emission from enteric fermentation mainly occurred in the nursery to finishing and gestating to lactating periods, which accounted for CH₄ production of 12.45 and 1.43 kg CO₂-eq, respectively (Table 2).

The indirect N₂O emission from manure management was the main contributing factor of GHG emissions in broiler chickens. Composting system in broiler production is generally used in South Korea. It has several benefits related to manure handling, odour control, manure moisture, pathogen control, and reduced CH₄ emission. Therefore, the improvement in efficiency of the composting system is important to mitigate indirect N₂O emission. For laying

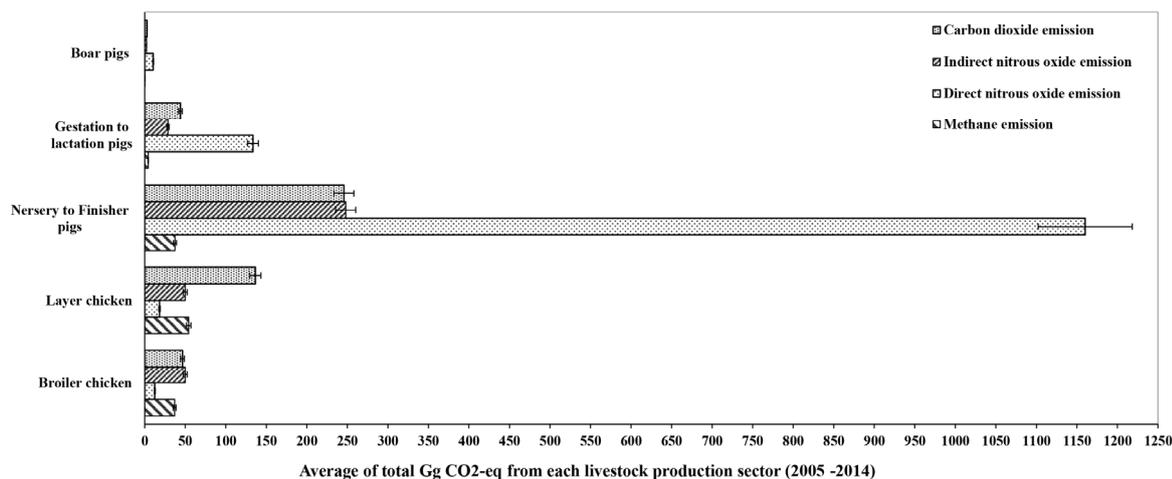


Figure 1. Average greenhouse gases emissions in poultry and pig production unit (from 2005 to 2014).

hens, CO₂ emission contributed the most to the emissions of GHG. In general, CO₂ is mainly generated through electrical heating system in poultry houses in South Korea. Carbon dioxide emissions can be reduced by replacing electrical heating systems of poultry houses with heating systems based on renewable energy sources, such as wind or solar energy.

Total CO₂ equivalent greenhouse gases emissions and emission intensity in pig production

Total GHG emissions from boars were 14.80 Gg-CO₂/yr from 2005 to 2014. The main contributor to GHG emissions was CH₄ from manure management, followed by CO₂ emission from manure management, direct on-farm energy uses and CH₄ enteric fermentation emission, which accounted for 8.47, 2.85, and 2.82 Gg-CO₂/yr, respectively (Table 4). In boars, direct N₂O emission was lower than indirect N₂O emission, at 0.003 and 0.67 Gg-CO₂/yr, respectively.

The greatest CH₄ emission came from pigs in the nursery to finishing period. Male pigs produced a smaller amount of CH₄ than those of female pigs. These results are in agreement with Dämmgen et al. (2012), who demonstrated that GHG emissions are affected by animal gender and possibly by pig management. According to Campbell et al. (1985) male breeding pigs with an energy intake from 5.39 to 8.60 Mcal digestible energy per day had a lower feed conversion ratio (FCR) than female pigs. Our result showed that breeding pigs had lower CH₄ emission compared with pigs in the nursery to finishing period, which was also consistent with Dämmgen et al. (2012). Many studies have reported that male pigs have a greater ability to gain body weight while decreasing their FCR than female pigs (Kyriazakis, 2011; Varley, 2009).

When comparing enteric fermentation in pigs from nursery to finishing stages and gestating to lactating sows,

we observed that the early period of pig production was associated with higher enteric fermentation emission than the reproductive period. It is due to lactating sows are normally fed a high fiber diet to reduce their feed intake. This practice allows more time for fermentation and thus methanogenesis in the gastrointestinal tract, specifically in the large intestine (Le Goff et al., 2002; Jørgensen et al., 2011). This could also be the case when adult sows are fed restricted diets (2 to 2.5 kg dry matter/d) during the dry period and pregnancy, which reduces excessive weight gain and prevents health problems during farrowing and lactation (NRC, 1998). Our study also demonstrated that female pigs had greater enteric CH₄ emission than male pigs, which is similar to the observation of Campbell et al. (1985). However, boars can increase N retention more than

Table 4. Average CO₂ equivalent GHG emissions (Gg-CO₂/yr) and emission intensities (kg-CO₂/yr/head) in pigs from 2005 to 2014

Sector	Nursery to finishing pigs	Gestating to lactating sows	Boars
CO ₂ equivalent GHG emissions (Gg-CO ₂ /yr)			
CH ₄ emission	934.35	107.57	8.46
Enteric CH ₄ emission	311.45	35.86	2.82
Direct N ₂ O emission	0.34	0.04	0.003
Indirect N ₂ O emission	73.88	8.51	0.67
Carbon dioxide emission	245.76	44.09	2.85
Total	1,565.79	196.06	14.80
Emission intensities (kg-CO ₂ yr/head)			
CH ₄ emission	11.25	11.25	11.25
Enteric CH ₄ emission	3.75	3.75	3.75
Direct N ₂ O emission	0.004	0.004	0.004
Indirect N ₂ O emission	0.89	0.89	0.89
Carbon dioxide emission	2.96	4.61	3.79
Total	18.85	20.51	19.69

GHG, greenhouse gases.

sows due to higher androgen concentration, resulting in increased anaerobic metabolism and feed efficiency (Tauson et al., 1998), and thus lower N₂O emission. For reproductive sows, the GHG emissions are typically greater during lactation than gestation. On average, emissions are approximately 12.1 g NH₃/d and 21.7 g NH₃/d for gestating and lactating sows, respectively (Philippe et al., 2015). The N excreta rate also depends on the balance between the animal's N consumption and its N retention in tissues (Portejoie et al., 2004; MacLeod et al., 2013). Furthermore, different categories of animals (e.g., adult females, adult males, and growing pigs) can have different N requirements (Dämmgen et al., 2012; MacLeod et al., 2013). In the current study, the N excreta rate decreased slightly between 2013 and 2014. A reduction in the N excreta rate can be caused by reduced crude protein in a pig's diet as its age increases (KFSS, 2007).

Carbon dioxide is an important GHG that can be generated during the production (MacLeod et al., 2013) because of heating, ventilation, feeding, manure handling, and washing (Hörndahl, 2008). Using the conversion of CH₄ and N₂O emissions from manure treatment systems to CO₂ equivalent emission (CO₂-Eq), CO₂-Eq increased from 6,733 kilotons in 2001 to 8,254 kt in 2009 (Ji and Park, 2012). This value for CO₂-Eq is lower than the results of our study due to differences in the pig populations in each location, as well as the animal category and default energy consumption value (MacLeod et al., 2013). In our study, we calculated the average energy consumption as 1.76 MJ kg/LW, including 1.13 MJ kg/LW for electricity and 0.63 MJ kg/LW for other power sources.

The total GHG emission intensities in nursery to finishing pigs, gestating to lactating sows, and boars were 18.85, 20.51, and 19.69 kg-CO₂/yr/head, respectively (Table 4). The gestating to lactating sows were the largest contributors to GHG emissions, particularly in CO₂ emission from direct on-farm energy uses associated with heating management to provide a proper temperature for piglets. According to Lammers et al. (2010), thermal control of farrowing facilities requires at least 225% more energy per pig space than other production facilities. It is generally accepted that farrowing buildings must be maintained at higher temperatures than other buildings to meet the thermal needs of young piglets until the age of 28 days. Farrowing buildings also have a lower density of pig spaces than other building types. However, as the pigs increase in size, less energy is used to heat the buildings and more is used for ventilation. Approximately 96% to 97% of the energy used for thermal control of farrowing pigs is related to providing heat. Conversely, approximately 86% of the energy used for thermal control of growing to finishing periods is associated with heating. In this study, we included weaning pigs, growing and finishing pigs in one

group. Therefore, the direct energy use in this subcategory has higher CO₂-eq emissions than shown in previous work.

Based on the current findings, it has been observed that the manure management is the major contributor of GHG emissions from the pig production in all categories. Anaerobic digestion of pig manure slurry for biogas production is of the most cost-effective methods to reduce emissions of GHG from pig farming. The evolved biogas can be used for energy supply which would further reduce the fossil fuel use and associated CO₂ emission. The emissions of GHG can also be reduced by other factors, such as housing conditions, manure management, and diet manipulation.

CONCLUSION

We estimated CH₄, N₂O, and CO₂ emissions from livestock agriculture in South Korea during 2005 to 2014 based on the data collected from 16 local administrative districts. We used a year of livestock population to calculate yearly emission fluctuations and summarized the average GHG emissions from poultry and three different pig producing periods. Our results demonstrated that GHG emissions from layer chickens are twice as large as for broiler chickens. The largest component of GHG emissions for broiler chickens is indirect N₂O emissions; whereas the largest component of GHG emissions for layer chickens is CO₂ emission resulted from direct on-farm energy uses. For pig production, the major contributor of GHG emission is CH₄ emissions during manure management in nursery to finishing pigs. The largest GHG emission intensity is associated with gestating to lactating sows. Overall, this study provides the baseline information about the emissions of GHG associated with poultry and pig production in South Korea, and emphasizes the need to reduce the emissions of GHG emissions through sustainable agricultural practices.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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