

Greenhouse Gas Emissions from Cattle Production Sector in South Korea

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ABSTRAK

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Negara Korea Selatan menyatakan akan mengurangi emisi gas rumah kaca sebanyak 30% dari level emisi saat ini pada tahun 2020. Penelitian ini dilakukan untuk mengevaluasi emisi gas rumah kaca dari sektor produksi sapi potong di Korea Selatan. Emisi gas rumah kaca dari aktivitas produksi sapi perah, sapi lokal Non-Korea dan sapi lokal Korea (Hanwoo) di 16 provinsi Korea Selatan selama sepuluh tahun (2005-2014) diestimasi menggunakan metode khusus berdasarkan Guidelines for National Greenhouse Gas Inventory of the IPCC (2006). Emisi yang dievaluasi dalam penelitian ini meliputi gas metan dari fermentasi enterik, gas metan dari pengelolaan kotoran, oksida nitrat dari pengelolaan kotoran dan karbon dioksida dari penggunaan energi secara langsung. Lebih dari 10 tahun terakhir, aktivitas produksi sapi Hanwoo merupakan penyumbang utama (83.52% dari total emisi sektor produksi ternak sapi) CH₄ dari fermentasi enteric, CH₄ dari pengelolaan kotoran, NO₂ dari pengelolaan kotoran dan NO₂ dari penggunaan energi secara langsung pada sektor peternakan sapi di Korea Selatan.

Kata Kunci: Metan, Oksida Nitrat, Karbondioksida, Sapi, Pemanasan Global

ABSTRACT

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South Korea has declared to reduce greenhouse gas emissions by 30% compared to the current level by the year 2020. The greenhouse gas emissions from the cattle production sector in South Korea were evaluated in this study. The greenhouse gas emissions of dairy cattle, Non-Korean native cattle and Korean native (Hanwoo) cattle production activities in 16 local administrative provinces of South Korea over a ten-year period (2005–2014) were estimated using the methodology specified by the Guidelines for National Greenhouse Gas Inventory of the IPCC (2006). The emissions studied herein included methane from enteric fermentation, methane from manure management, nitrous oxide from manure management and carbon dioxide from direct on-farm energy use. Over the last ten years, Hanwoo cattle production activities were the primary contributor of CH₄ from enteric fermentation, CH₄ from manure management, NO₂ from manure management and CO₂ from on-farm energy use in the cattle livestock sector of South Korea, which comprised to 83.52% of total emissions from cattle production sector.

Key Words: Methane, Nitrous Oxide, Carbon Dioxide, Cattle, Global Warming

INTRODUCTION

Greenhouse gas (GHG) emissions from human activities become a focus of worldwide attention because of global warming issues. With global warming, the equilibrium of ecosystems is threatened by climate change. The agricultural sector contributes 18% (7.1 billion tonnes CO₂ equivalent) to the total global greenhouse gas emissions (FAO 2006). Although agricultural activity contributes only 9% to global CO₂ emissions, agriculture generates 65% of human-related nitrous oxide (N₂O) and 35% of methane (CH₄) with global warming potentials (GWPs) of 298-fold and 25-

fold that of CO₂, respectively (USEPA 2014; IPCC 2006; Smith et al. 2007). South Korea pledged to reduce greenhouse gas emissions by 30% below the current levels by 2020 or by 4% below the levels of 2005 (UNFCCC 2011; Gerber et al. 2013). Livestock production is a critical contributor in agricultural activity that produces greenhouse gases and contributes approximately 42% to the total GHG emissions, with 28% of the emissions directly from enteric fermentation and 14% from indirect emissions due to the handling, storage, and land application of manure (AAFCCT 2000).

Production of cattle is an important part of economic growth of the livestock industry as it meets the increasing demand of meat and milk products. However, along the production, greenhouse gases are emitted. Few studies have estimated GHG emissions from livestock sector that follow the IPCC guidelines. Merino et al. (2011) inventoried the regional methane and nitrous oxide emissions from ruminant livestock in Basque country, and Patra (2014) studied the trends and projected estimation of GHG emissions from Indian livestock in comparison with the global GHG emissions and those from developing countries. In South Korea, Ji & Park (2012) found that the annual growth rates of enteric CH₄ emissions and CH₄ and N₂O emissions from manure management from 1990 to 2009 were 1.7%, 2.6% and 3.2%, respectively. Lee & Lee (2003) investigated national methane emissions from the enteric fermentation of livestock, and Jo et al. (2015) estimated methane emissions factor from enteric fermentation of Hanwoo steers. Amon et al. (2006) estimated GHG emissions from different management system of dairy cattle. In South Korea, Korean native (Hanwoo) cattle population is already be distinguished from the other beef producing cattle breed population. Other source of beef production is the dairy cattle steers which is categorized as Non-Korean native cattle. However, the information has not been obtained for recent GHG emissions from cattle production activities in South Korea. Therefore, the aim of this study was to estimate the emissions of greenhouse gases from the cattle production sector, including estimates for on-farm energy use, in South Korea.

MATERIALS AND METHODS

Scope and activity data

This study focused on three primary emission sources in cattle production activities: Emissions from

enteric fermentation, emissions from manure management, and emissions from direct on-farm energy use. Methane was emitted from enteric fermentation and manure management, nitrous oxide from manure management and carbon dioxide from on-farm energy use. Data of livestock populations in South Korea were adopted from the Korean Statistical Information Services. Populations of cattle were based on the average of each annual quartile. Cattle population data between 2005 and 2014 are shown in Table 1. The cattle were divided into three categories (breed, age and sex). The breed category was divided into three subcategories (Hanwoo, beef, and dairy cattle), the age category was divided into three subcategories (under 1 y, 1-2 y, and over 2 y), and the sex was divided into two subcategories (male and female), except for the dairy cattle. The population estimates are presented for 16 local administrative provinces in South Korea.

Estimation of greenhouse gas emissions

Current assessment used a methodology specified in the Guidelines for National Greenhouse Gas Inventory (IPCC 2006) and the Greenhouse gas emissions from ruminant supply chains (Opio et al. 2013). The emissions were assessed in 16 local administrative provinces of South Korea. Global Warming Potentials (GWPs), based on the 4th Assessment Report of the IPCC (IPCC 2006), were used to convert N₂O and CH₄ values to CO₂-eq values. Consequently, the GWPs of 25 and 298 were used for CH₄ and N₂O, respectively.

Approaches used to estimate the emissions from cattle production were Tier-1 and Tier-2 methods in the IPCC guidelines. In this study, the different value of enteric fermentation factor was used for Hanwoo and Non-Korean native cattle since Korea has different category of beef production cattle. Default emission factors for the Tier-1 method were provided by the IPCC (2006). For some approaches using Tier-2

Table 1. Cattle population in South Korea (2005-2014)

Year	Korean native (Hanwoo) cattle (heads)	Non-Korean native cattle (heads)	Dairy cattle (heads)
2005	1,582,446	181,301	487,882
2006	1,781,256	177,743	471,214
2007	1,990,379	170,248	456,387
2008	2,232,247	165,220	446,319
2009	2,432,454	154,976	442,373
2010	2,709,201	157,362	435,048
2011	2,839,829	142,216	401,628
2012	2,937,828	124,854	412,828
2013	2,884,541	113,318	421,135
2014	2,724,879	92,275	427,782

Table 2. Approaches to estimate GHG emissions from cattle production in South Korea (2005-2014)

Emission sector	Korean native (Hanwoo) cattle	Non-Korean native cattle	Dairy cattle
CH ₄ emissions from enteric fermentation	Tier-2	Tier-2	Tier-2
CH ₄ emissions from manure management	Tier-2	Tier-2	Tier-1
N ₂ O emissions from manure management	Tier-1	Tier-1	Tier-1
CO ₂ emissions from direct on-farm energy use for livestock	Tier-1	Tier-1	Tier-1

method, country-specific information was required. The estimations of emission factors for the Tier-2 method were adopted from the IPCC guidelines. Characteristics of the approaches used to estimate GHG emissions for cattle production are shown in Table 2. The estimation was conducted in 3 steps. In step 1, cattle population was classified into subgroups and each subgroup was characterized. In step 2, emission factor was estimated for each subgroup in kilograms of gas emission per animal per year.

In step 3, to estimate the emissions for the different subgroups, the emission factors of each subgroup were multiplied by the population size of that subgroup; the emissions of the subgroups were then summed to estimate total emission.

RESULTS AND DISCUSSION

CH₄ emission from enteric fermentation

Cattle consume organic matter that is degraded by rumen microbes with the production of CH₄ as a final product of metabolism; thus, enteric fermentation in cattle is a source of CH₄ emission. Tier-2 method was used in this estimation. Tier-2 methodology is more appropriate than the Tier-1 (Höglund-Isaksson 2012).

Emission factors for methane enteric fermentation from cattle in South Korea are provided in Table 3, which was used to estimate enteric methane emission.

CH₄ emissions from cattle enteric fermentation of South Korea are shown in Table 4. Annual CH₄ emissions from the enteric fermentation of dairy cattle in the 16 provinces of South Korea between 2005 and 2014 decreased about 17.41%. However, it starts to increase after 2011. The highest CH₄ emissions from dairy cattle enteric fermentation was recorded in Gyeonggi. In seven of the provinces, the CH₄ emissions from dairy cattle enteric fermentation decreased in 2011 but then increased in 2014, compared to the emission in 2011. The local administrative provinces with decreased emission from dairy cattle enteric fermentation in 2014 compared to that in 2005 was Daegu (-56%), Daejeon (-100%) and Jeju (-18%).

The local administrative province with increased CH₄ emissions from dairy cattle enteric fermentation in 2014 compared to that in 2005 was Chungcheongnam (+8%). From enteric fermentation, dairy cattle emitted 1.19 Mt CO₂-eq in 2001 (Lee & Lee 2003), whereas in this study, dairy cattle emitted 1.21 Mt CO₂-eq in 2014. The total methane emissions from enteric fermentation did not increase significantly because the population remained constant during the last ten years.

Table 3. Emission factors to estimate methane emissions from enteric fermentation of cattle in South Korea

Cattle	Emission factor (kg CH ₄ /head/year)			
Korean native (Hanwoo)	under 1 year	1~2 years	2 years and over	
	Male	36.2	71.5	76.1
	Female	34.3	63.6	73.1
Non-Korean native	under 1 year	1~2 years	2 years and over	
	Male	51.5	69.1	98.3
	Female	23.0	50.7	63.5
Dairy	under 1 year	1~2 years	2 years and over	
		41.24	53.55	53.40

Table 4. CH₄ emissions from the enteric fermentation of cattle in South Korea (2005-2014)

Year	Korean native (Hanwoo) cattle (Mt CO ₂ -eq/year)	Non-Korean native cattle (Mt CO ₂ -eq/year)	Dairy cattle (Mt CO ₂ -eq/year)	Total (Mt CO ₂ -eq/year)
2005	2.33	0.26	1.33	3.91
2006	2.64	0.25	1.27	4.17
2007	2.96	0.25	1.24	4.44
2008	3.35	0.24	1.20	4.79
2009	3.67	0.23	1.19	5.09
2010	4.10	0.23	1.18	5.51
2011	4.31	0.22	1.09	5.62
2012	4.47	0.19	1.16	5.82
2013	4.44	0.18	1.19	5.80
2014	4.21	0.14	1.21	5.57

Between 2005 and 2014, CH₄ emissions from the enteric fermentation of Non-Korean native cattle in South Korea decreased only about 0.46% or about 0.12 Mt CO₂-eq. In all 16 provinces except for Busan, less CH₄ was emitted from Non-Korean native cattle enteric fermentation in 2005 compared to that in 2014. The largest CH₄ emissions decreasing between 2005 to 2014 was from Non-Korean native cattle in Chungcheongbuk with a decrease of 0.019 CO₂-eq or about 52% compare to the initial. Local province with an increase of CH₄ emissions from Non-Korean native cattle enteric fermentation was Busan that increased the emission by about 10% during the last ten years. From the enteric fermentation of Hanwoo cattle in South Korea, annual CH₄ emissions increased by about 91.6% between 2005 and 2012 then decreased by about 5.8% in 2014. Compared to the emissions in 2005, all 16 local administrative provinces showed higher CH₄ emissions from the enteric fermentation of Hanwoo cattle in 2014. Among the 16 local administrative provinces in 2014, Gyeongsangbuk recorded as a province with highest CH₄ emissions from Hanwoo cattle enteric fermentation approximately by 0.91 Mt CO₂-eq. For the enteric fermentation of Hanwoo cattle between 2005 and 2014, local administrative provinces with an increase in the rate of CH₄ emissions above 100% were Incheon (+22,560.75 Mt CO₂-eq, +258%), Gyeonggi (+190.125 Mt CO₂-eq, +119%), and Jeollabuk (+272,742.75 Mt CO₂-eq, +117%). Lee & Lee (2003) reported that methane emission from the enteric fermentation of Hanwoo cattle was 1.54 Mt in 2001, whereas we found that methane emissions were 4.21 Mt CO₂-eq in 2014 from the enteric fermentation of Hanwoo. The largest contribution of methane from enteric fermentation was from Hanwoo cattle because of the highest population growth rate during ten-year period. Johnson & Johnson (1995) reported that many factors influence methane

emissions from cattle, including the level of feed intake, type of carbohydrate in the diet, feed processing, addition of lipids or ionophores to the diet, and alterations in the ruminal microflora. Furthermore, the results of this study (4.21 Mt CO₂-eq from 2,724,879 head of Hanwoo cattle in a year) were consistent with those reported by Basarab et al. (2005), who reported that 8.34 Mt CO₂-eq were emitted from the enteric fermentation of 6,474,350 head of Non-Korean native cattle in a year (using a Tier-2 method).

CH₄ emission from manure management

Emissions of nitrous oxide from the management of Non-Korean native cattle manure were direct and indirect. Because the available data were limited for each variable, this assessment used Tier-1 method to estimate nitrous oxide emission. Annual average N excretion per head per year (N_{ex}) value were used to estimate direct N₂O emission. The fraction of total annual nitrogen excretion for livestock and the emission factor value that were used in this assessment were 1 and 0.006 N₂O-N/kg N, respectively. These values were from the default values of the IPCC (2006). Methane emission factor is provided in Table 5 for the estimation of emission from the manure management of Non-Korean native cattle in South Korea. To evaluate the contribution of cattle production sector in South Korea to global warming, the global warming potentials of the GHG emissions were converted into units of Mt CO₂-eq.

CH₄ emission from manure management of cattle in South Korea between 2005 and 2014 are presented in Table 6. CH₄ emission from manure management of dairy cattle decreased by about 9.46% in between 2005 to 2014. However, the lowest emission occurred in 2011 (0.0822 Mt CO₂-eq), with a slight increase

Table 5. Emission factors to estimate methane emissions from manure management of Non-Korean native cattle in South Korea

Cattle	Emission factor (kg CH ₄ /head/year)		
	under 1 year	1~2 years	Over 2 years
Hanwoo			
Male	0.60	1.01	0.94
Female	0.57	0.90	0.91
Beef			
Male	0.86	0.97	1.22
Female	1.10	1.32	1.62
Dairy			
	0.99	1.16	2.53

thereafter. Gyeonggi was the local administrative province with the highest CH₄ emissions (8.176 kt CO₂-eq) from manure management in 2014. About 15 local administrative provinces showed a slight decrease in CH₄ emissions from dairy cattle manure management with an annual growth rate of -1.02%, and one local administrative province (Chungcheongnam) showed an increase from 3.76 kt CO₂-eq in 2005 to 4.05 kt CO₂-eq in 2014.

Similarly, CH₄ emission from manure management of Non-Korean native cattle in South Korea between 2005 and 2014 decreased approximately 49% with an annual growth rate of -7.16% (Table 6). All the 16 local administrative provinces showed a decrease in CH₄ emission from Non-Korean native cattle manure management between 2005 and 2014. Gyeonggi was the local administrative province with the highest emissions of approximately 0.872 kt CO₂-eq from cattle manure management in 2014 among the 16 local administrative provinces.

CH₄ emission from manure management of Hanwoo cattle in South Korea increased between 2005 and 2014

by about 0.0252 MtCO₂-eq or 78%. Compared to the other local administrative districts, Gyeongsangbuk showed the highest CH₄ emissions from the manure management of Hanwoo cattle between 2005 and 2014 (12.32 kt CO₂-eq). The local administrative provinces with increased emissions of CH₄ above 100% from the manure management of Hanwoo cattle between 2005 and 2014 were Incheon (+39 kt CO₂-eq, +283.89%), Gyeonggi (+322.51 kt CO₂-eq +127.74%), Jeollabuk (+458.99 ktCO₂-eq, +122.92%), and Jeju (+39.80 ktCO₂-eq, +122.92%). Annual growth rate for CH₄ emission was 8.33% from manure management of Hanwoo cattle in South Korea between 2005 and 2014. Among the three types of cattle production in South Korea, methane emission increased only from the manure management of Hanwoo cattle.

N₂O emission from manure management

N₂O emissions from manure management of cattle are shown in Table 7. Emission of N₂O during manure

Table 6. CH₄ emission from the manure management of cattle in South Korea (2005-2014)

Year	Korean native (Hanwoo) cattle (Mt CO ₂ -eq/year)	Non Korean native cattle (Mt CO ₂ -eq/year)	Dairy cattle (Mt CO ₂ -eq/year)	Total (Mt CO ₂ -eq/year)
2005	0.0320	0.0044	0.0243	0.0607
2006	0.0361	0.0044	0.0234	0.0639
2007	0.0405	0.0042	0.0226	0.0673
2008	0.0457	0.0040	0.0220	0.0718
2009	0.0501	0.0037	0.0218	0.0757
2010	0.0559	0.0038	0.0215	0.0813
2011	0.0587	0.0035	0.0201	0.0822
2012	0.0609	0.0030	0.0211	0.0851
2013	0.0605	0.0027	0.0216	0.0848
2014	0.0572	0.0022	0.0220	0.0815

Table 7. N₂O emissions from the manure management of cattle in South Korea (2005-2014)

Year	Korean native (Hanwoo) cattle (Mt CO ₂ -eq/year)	Non Korean native cattle (Mt CO ₂ -eq/year)	Dairy cattle (Mt CO ₂ -eq/year)	Total (Mt CO ₂ -eq/year)
2005	0.3112	0.0541	0.1440	0.5093
2006	0.3503	0.0530	0.1391	0.5424
2007	0.3914	0.0508	0.1347	0.5769
2008	0.4390	0.0493	0.1318	0.6200
2009	0.4784	0.0462	0.1306	0.6552
2010	0.5328	0.0469	0.1284	0.7081
2011	0.5585	0.0424	0.1186	0.7195
2012	0.5777	0.0372	0.1219	0.7369
2013	0.5673	0.0338	0.1243	0.7254
2014	0.5359	0.0275	0.1263	0.6897

treatment occurs in two forms, direct and indirect. Total N₂O emission from manure management of dairy cattle between 2005 and 2014 decreased by about 14%. The lowest N₂O emission from dairy cattle manure management occurred in 2011, which increased thereafter. The largest decrease in percent emission was in Daejeon (-100%), followed by Daegu (-13.93%), whereas Chungcheongnam was the local administrative district with the largest increase in N₂O emission from manure management of dairy cattle by approximately 114.9% in 2014 compared to that in 2005. Total N₂O emission from manure management of Non-Korean native cattle between 2005 and 2014 decreased by approximately 49.10%. Local administrative district with the highest emission in 2014 was Gyeonggi (11,033 kt CO₂-eq), whereas the lowest emissions was in Daejeon (0 kt CO₂-eq). Those all local administrative districts showed a decrease in N₂O emission from non-Korean native cattle manure management. Daejeon showed the largest decrease of about 100% and Seoul with the smallest decrease of about 6.36%. Local administrative provinces that had decreases in emission above 30% during last ten years were Incheon, Gwangju, Daejeon, Ulsan, Gyeonggi, Gangwon, Chungcheongbuk, Chungcheongnam, Jeollabuk, Jeollanam, Gyeongsangbuk, Gyeongsangnam, and Jeju, with decreases rate of approximately 83.79, 92.27, 100.00, 79.99, 32.02, 46.18, 57.52, 37.63, 67.67, 44.19, 51.14, 78.20, and 78.56%, respectively. Local administrative provinces with decrease rate below 30% were Seoul (6.36%), Busan (6.86%) and Daegu (25.39%).

In contrast, total N₂O emission from manure management of Hanwoo cattle increased. Compared to emission in 2005, N₂O emissions from Hanwoo cattle manure management in 2014 increased by

approximately 72.2%, although the emission decreased from 2012 by approximately (7.2%). Those 16 local administrative provinces had increased emission from manure management of Hanwoo cattle. Local administrative province with the highest N₂O emission in 2014 was Gyeongsangbuk (0.11 Mt CO₂-eq).

CO₂ emissions from direct on-farm energy use for cattle production

Direct on-farm energy use in cattle production is the use of energy for the milking, ventilation, heating and lighting, heating of water, and watering and feeding of animals. Three years of CO₂ emissions from the direct on-farm energy used for cattle production in South Korea between 2005 and 2014 are shown in Table 8. The CO₂ emissions from direct on-farm energy use for dairy cattle in South Korea decreased from 62,050.02 t CO₂ in 2005 to 51,272.13 t CO₂ in 2011, with an increase to 55,471.87 t CO₂ in 2014. The local province of Chungcheongnam was the only province to show an increase in CO₂ emissions from direct on-farm energy used in dairy cattle production of approximately 568.31 t CO₂ for the ten-year period. In the other 15 local administrative provinces, the CO₂ emissions from direct on-farm energy use for dairy cattle production in South Korea decreased. The highest emissions of CO₂ for dairy cattle production were in Gyeonggi (21,580.82 t CO₂) in 2014; however, these emissions were decreased compared to those in 2005 by approximately 23,969.34 t CO₂. The decrease in percent CO₂ emissions from the direct on-farm energy use in dairy cattle production between 2005 and 2014 ranged from 6.01% (Busan) to 100% (Daejeon), with an average decrease of approximately 23.20%.

Table 8. CO₂ emissions from the direct on-farm energy use for cattle production in South Korea (2005-2014)

Year	Korean native (Hanwoo) cattle (Mt CO ₂ -eq/year)	Non-Korean native cattle (Mt CO ₂ -eq/year)	Dairy cattle (Mt CO ₂ -eq/year)	Total (Mt CO ₂ -eq/year)
2005	0.1490	0.0172	0.0621	0.2283
2006	0.1690	0.0172	0.0598	0.2461
2007	0.1901	0.0165	0.0579	0.2646
2008	0.2166	0.0159	0.0566	0.2891
2009	0.2377	0.0149	0.0561	0.3087
2010	0.2677	0.0154	0.0553	0.3383
2011	0.2822	0.0144	0.0513	0.3479
2012	0.2912	0.0124	0.0533	0.3570
2013	0.2900	0.0116	0.0546	0.3561
2014	0.2771	0.0095	0.0555	0.3421

The emissions from direct on-farm energy use of Non-Korean native cattle production in South Korea decreased by about 0.44% during last ten years. All the 16 local administrative provinces showed decreases in the emissions from direct on-farm energy use for Non-Korean native cattle production. The local administrative district showed the highest emissions from direct on-farm energy use in Non-Korean native cattle production in 2014 was Gyeonggi (3,559.52 kt CO₂-eq), and the lowest emissions was in Daejeon (0 t CO₂-eq) since Non-Korean native cattle population has not been growth in Daejeon on 2012. CO₂ emission decreased by more than 50% during the last ten-year period in 7 local administrative provinces, which were Incheon (-81.94%), Gwangju (-91.87%), Daejeon (-100%), Ulsan (-80.52%), Chungcheongbuk (-51.96%) Jeollabuk (-63.28%), Gyeongsangnam (-75.11%), and Jeju (-79.89%). The decreases in CO₂ emission were less than 50% in 8 local administrative provinces, which were Seoul (-15.16%), Busan (-23.80%), Daegu (-10.94%), Gyeonggi (-25.55%), Gangwon (-47.45%), Chungcheongnam (-28.85%), Jeollanam (-43.11%), and Gyeongsangbuk (-44.75%). Decrease in CO₂ emission from direct on-farm energy use in Non-Korean native cattle production was likely because of the decrease in the population of Non-Korean native cattle in those areas. Average decrease in CO₂ emission from direct on-farm energy use in Non-Korean native cattle production between 2005 and 2014 in South Korea was approximately 54.01%.

In contrast to that of Non-Korean native cattle production, CO₂ emission from the on-farm energy use in Hanwoo cattle production increased from 2005 to 2012, then thereafter start to decrease. CO₂ emission from direct on-farm energy use in the production of Hanwoo cattle in 2014 increased by approximately 85%

compared to that in 2005. Local administrative district with the highest CO₂ emission from direct on-farm energy use in the production of Hanwoo cattle in 2014 was Gyeongsangbuk (59,820.40 kt CO₂-eq). Seoul was the district with the lowest CO₂ emission of approximately 8.23 kt CO₂-eq. Four local administrative provinces that increase in CO₂ emission from direct on-farm energy use in Hanwoo cattle production above 100% during the last ten years were Incheon (283.89%), Gyeonggi (127.74%), Jeollabuk (122.92%) and Jeju (102.78%). Development of Hanwoo cattle industry has been focused in these areas during last ten years, and therefore, the energy used for operating farm facilities increased as the increase of Hanwoo cattle population.

Global warming potential of GHG emission from cattle production

Global warming potential of the GHG emission from cattle production in South Korea between 2005 and 2014 is shown in Figure 1. Total global warming potential of the GHG emission from cattle production in South Korea was approximately 60.7 Mt CO₂-eq between 2005 and 2014. The GWPs of emission increased from 4.67 Mt CO₂-eq in 2005 to the highest emission in 2012 of about 6.97 kt CO₂-eq, which then decreased to 6.65 Mt CO₂-eq in 2014. The largest contribution to emission from cattle production was methane from enteric fermentation, which was approximately 50.72 Mt CO₂-eq and comprised 83.52% of the total emission. The contribution from N₂O from manure management was less (6.173 Mt CO₂-eq, 10.16% of total emissions), from CO₂ from direct on-farm energy use was 3.078 Mt CO₂-eq (5.1% of total

emissions) and methane from manure management was 0.754 Mt CO₂-eq (1.2% of total emissions).

During the ten-year period (2005-2014), total emission from enteric fermentation from production of cattle in South Korea increased by approximately 42%. For comparison, GIR (2013) reported that total emission from enteric fermentation in a 10-year period in South Korea increased by approximately 9.7%. The estimatic

increase in emission from enteric fermentation of cattle in the ten years of this study might represent the increase in the contribution of cattle production to total methane emission. The differences between the two estimates were primarily because the IPCC Tier-2 model significantly overpredicts cattle GE intake at higher level intake. This over predict was also reported by Jo et al. (2015) with Hanwoo steers study.

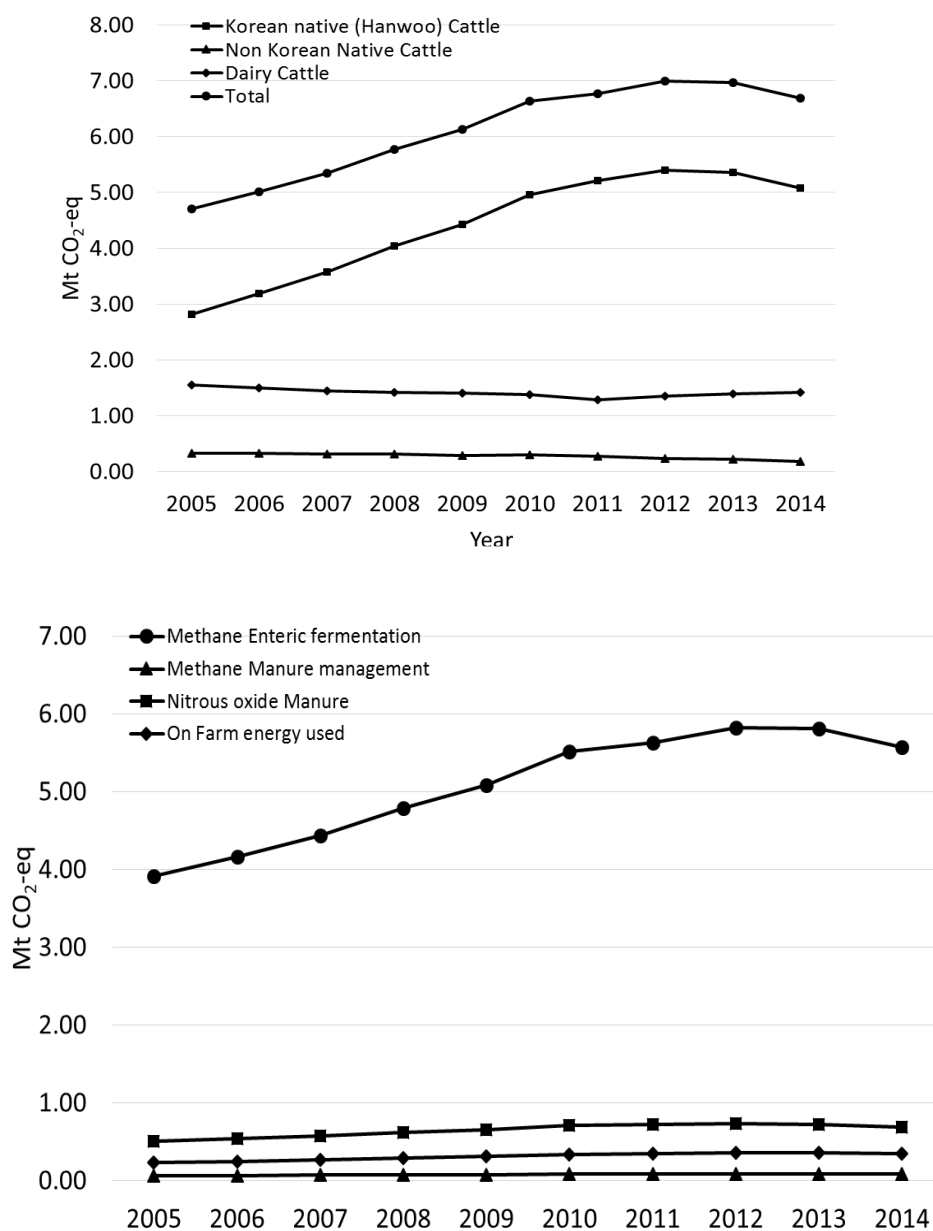


Figure 1. Global warming potential of GHG emission by cattle type (A) and by emission type (B) from cattle livestock production activities in South Korea in between 2005-2014.

Furthermore, it is consensused that the enteric fermentation of cattle is the largest source of CH₄ emission in the livestock sector (FAO 2006).

The highest emission of greenhouse gases during the ten-year period (2005-2014) of approximately 44.081 Mt CO₂-eq was generated in the production of Hanwoo cattle, which was followed by dairy cattle production (13.84 Mt CO₂-eq) and Non-Korean native production (2.80 kt CO₂-eq). Compared with the level in 2005, the greenhouse gas emission from production of Hanwoo cattle have not reached the declared target level of a 30% reduction by 2020 (4% lower than the 2005 level) with 5.08 Mt CO₂-eq produced in 2014, which was 80% higher than that in 2005 (2.82 Mt CO₂-eq). However, target levels for the reduction in greenhouse gas emission from the production of both Non-Korean native beef and dairy cattle were reached. Emissions from production of Non-Korean native cattle were 0.18 Mt CO₂-eq in 2014, which was 45% lower than that in 2005 (0.33 Mt CO₂-eq).

Annual average and annual growth rate of GHG emission from cattle production in South Korea between 2005 and 2014 are shown in Figure 2. Annual average GHG emission from Hanwoo cattle production was 4,408.13 kt CO₂-eq/y, which was higher than that Non-Korean native cattle production (280.46 kt CO₂-eq/y) and dairy cattle production (1,384.17 kt CO₂-eq/y) from production of Hanwoo cattle was 6.06% between 2005 and 2014. By contrast, average annual growth rate of GHG emission from beef and dairy cattle production was -5.83% and -0.92%, respectively (eq/y). Average annual growth rate of GHG emission

Annual average GHG emission from the production of Hanwoo beef and dairy cattle by province in South

Korea between 2005 and 2014 are shown in Figure 3. Local administrative district with the highest annual average GHG emission from the production of Hanwoo cattle was Gyeongsangbuk (874,088.35 t CO₂-eq/y), whereas Seoul had the lowest emissions (309.28 t CO₂-eq/y). In 8 local administrative provinces, annual average GHG emission from the production of Hanwoo cattle was above 200,000 t CO₂-eq/y, which included Gyeonggi (329,236.88 t CO₂-eq/y), Gangwon (333,708.28 t CO₂-eq/y), Chungcheongbuk (276,040.47 t CO₂-eq/y), Chungcheongnam (545,616.62 t CO₂-eq/y), Jeollabuk (483,579.63 t CO₂-eq/y), Jeollanam (717,474.71 t CO₂-eq/y), Gyeongsangbuk (874,088.35 t CO₂-eq/y), and Gyeongsangnam (459,675.92 t CO₂-eq/y). The highest annual growth rate in GHG emissions from the production of Hanwoo cattle was in Incheon (12.73% per year), and the lowest annual growth rate was in Seoul (1.99% per year). In contrast to the emission from production of Hanwoo cattle, the highest annual average of GHG emission from beef and dairy cattle production was in Gyeonggi Province, with 102,811.80 and 579,239.60 t CO₂-eq/y, respectively. Daejeon was the local administrative province with the lowest annual growth rates for the emissions from beef and dairy cattle production, with approximately -27.72% and -47.81% per year, respectively. From this study, the local towns primarily produced the GHG emission from the production of Hanwoo cattle compared with the metropolitan areas. The annual growth rate of GHG emissions from production of Hanwoo cattle was considerably higher than that of beef and dairy cattle production.

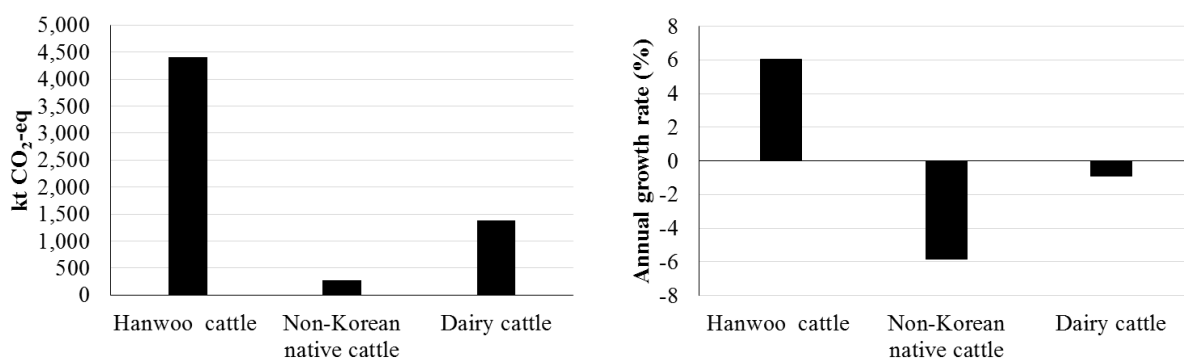


Figure 2. Annual average (A) and annual growth rate (B) of GHG emission from cattle production in South Korea (2005-2014).

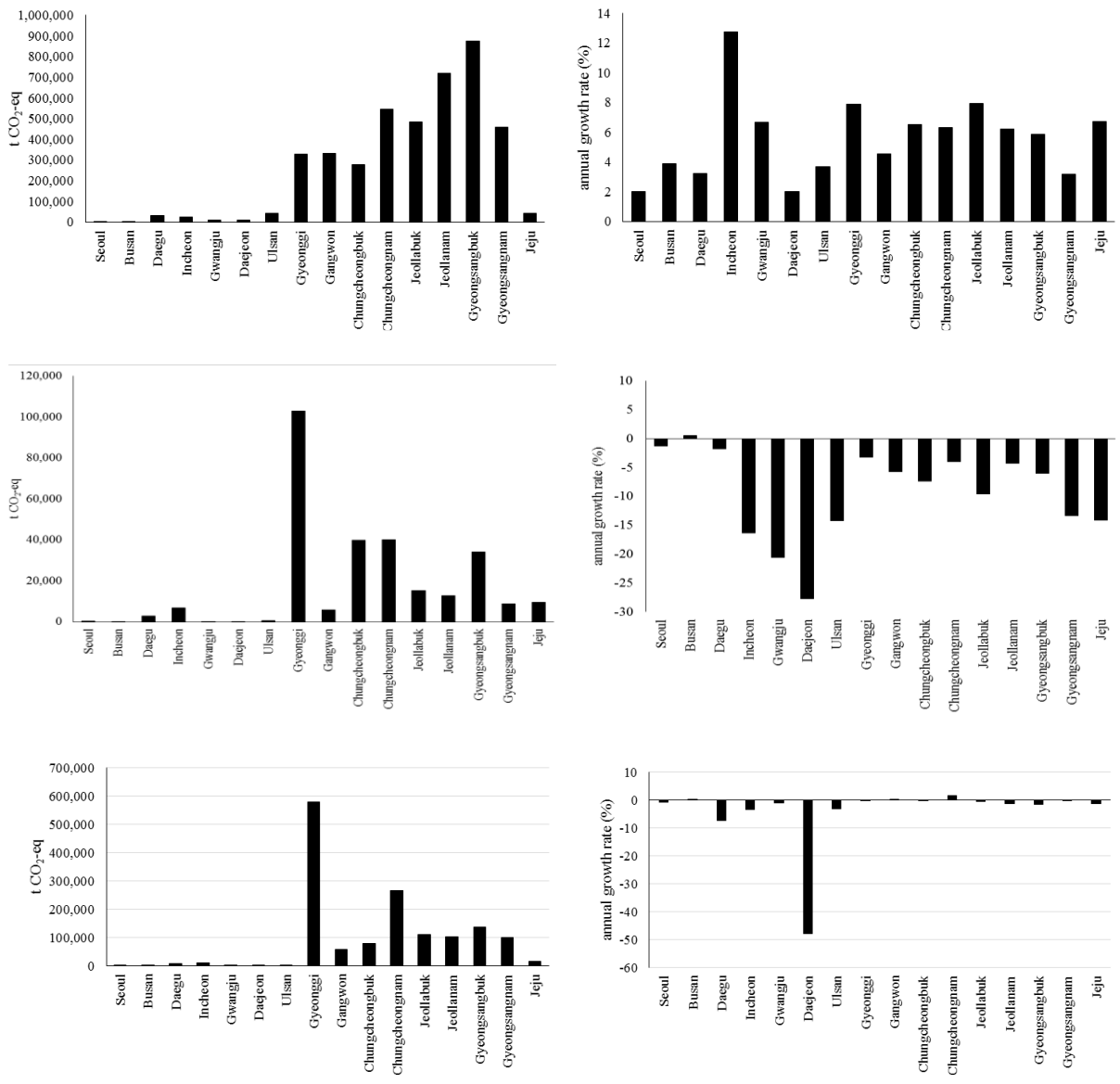


Figure 3. Annual average and annual growth rate of GHG emission from the production of Hanwoo cattle (A), Non-Korean native cattle (B) and Dairy cattle (C) by province in South Korea (2005-2014).

Results of correlation analyses between the cattle type and GHG emission in South Korea from 2005 to 2014 are provided in Table 9. Correlation coefficient of CH₄ emission from the enteric fermentation of Hanwoo cattle and the total CH₄ emission was 0.999, which was higher than that Non-Korean native cattle (-0.823) or dairy cattle (-0.947). Correlation coefficient of CH₄ emission from the manure management of Hanwoo cattle and total CH₄ emission was 0.998, which was higher than that Non-Korean native cattle (-0.817) or dairy cattle (-0.944). Correlation coefficient of NO₂ emission from manure management of Hanwoo cattle and total NO₂ emission was 0.956, which was higher

than that Non-Korean native cattle (-0.715) or dairy cattle (-0.934). Correlation coefficient of CO₂ emission from on-farm energy use in production of Hanwoo cattle and total CO₂ emission was 0.999, which was higher than that Non-Korean native cattle (-0.819) or dairy cattle (-0.951). Correlation coefficient was 0.999 between the global warming potential of GHG emission from production of Hanwoo cattle and total global warming potential of GHG emission, which was higher than that Non-Korean native cattle (-0.818) or dairy cattle (-0.949). Those showed that production of Hanwoo cattle was the primary contributor to total CH₄ emission from enteric fermentation, CH₄ emission from

Table 9. Correlation analysis between cattle type and GHG emission in South Korea from 2005 to 2014

	CH ₄ enteric fermentation	CH ₄ manure management	NO ₂ manure management	CO ₂ on farm energy use	Global warming potential
Hanwoo	0.999	0.998	0.956	0.999	0.999
Non-Korean native cattle	-0.823	-0.817	-0.715	-0.819	-0.818
Dairy	-0.947	-0.944	-0.934	-0.951	-0.949

manure management, NO₂ emission from manure management, CO₂ emission from on-farm energy use, and total global warming potential of GHG emission from cattle production sector in South Korea.

However, both overestimates and underestimates of emissions were possible in this study. Kebreab et al. (2008) reported that the IPCC values result in an overestimate of emissions by approximately 12.5% and an underestimate by approximately 9.8% for dairy and feedlot cattle, respectively. In this study, about 31.18% overestimates of enteric fermentation occurred which was higher than the one reported by GIR (2013).

CONCLUSION

Emissions of greenhouse gases from the cattle production sector in South Korea increased year to year and failed to reach the target pledge of a 30% reduction compared with current levels. Production of Hanwoo cattle was the primary contributor to CH₄ emission from enteric fermentation, CH₄ emission from manure management, NO₂ emission from manure management and CO₂ emissions from on farm energy use in the cattle production sector of South Korea during the ten-year period of this study. Proper mitigation is required in the cattle production sector to meet the target pledge for emission in 2020. Mitigation options for reductions in emission should focus on the production of Hanwoo cattle because of the significant contributions to greenhouse gas emission in South Korea.

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