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Methane and Nitrous Oxide Emissions from Livestock Agriculture in 16 Local Administrative Districts of Korea

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ABSTRACT: This study was conducted to evaluate methane (CH_4) and nitrous oxide (N_2O) emissions from livestock agriculture in 16 local administrative districts of Korea from 1990 to 2030. National Inventory Report used 3 yr averaged livestock population but this study used 1 yr livestock population to find yearly emission fluctuations. Extrapolation of the livestock population from 1990 to 2009 was used to forecast future livestock population from 2010 to 2030. Past (yr 1990 to 2009) and forecasted (yr 2010 to 2030) averaged enteric CH_4 emissions and CH_4 and N_2O emissions from manure treatment were estimated. In the section of enteric fermentation, forecasted average CH_4 emissions from 16 local administrative districts were estimated to increase by 4%-114% compared to that of the past except for Daejeon (-63%), Seoul (-36%) and Gyeonggi (-7%). As for manure treatment, forecasted average CH_4 emissions from the 16 local administrative districts were estimated to increase by 3%-124% compared to past average except for Daejeon (-77%), Busan (-60%), Gwangju (-48%) and Seoul (-8%). For manure treatment, forecasted average N_2O emissions from the 16 local administrative districts were estimated to increase by 10%-153% compared to past average CH_4 emissions except for Daejeon (-60%), Seoul (-4.0%), and Gwangju (-0.2%). With the carbon dioxide equivalent emissions (CO_2-Eq), forecasted average CO_2-Eq from the 16 local administrative districts were estimated to increase by 31%-120% compared to past average CH_4 emissions except Daejeon (-65%), Seoul (-24%), Busan (-18%), Gwangju (-8%) and Gyeonggi (-1%). The decreased CO_2-Eq from 5 local administrative districts was only 34 kt, which was insignificantly small compared to increase of 2,809 kt from other 11 local administrative districts. Annual growth rates of enteric CH_4 emissions, CH_4 and N_2O emissions from manure management in Korea from 1990 to 2009 were 1.7%, 2.6%, and 3.2%, respectively. The annual growth rate of total CO_2-Eq was 2.2%. Efforts by the local administrative offices to improve the accuracy of activity data are essential to improve GHG inventories. Direct measurements of GHG emissions from enteric fermentation and manure treatment systems will further enhance the accuracy of the GHG data. (**Key Words:** Greenhouse Gas, Methane, Nitrous Oxide, Carbon Dioxide Equivalent Emission, Climate Change)

INTRODUCTION

Livestock population in Korea has been increased with a rise in national per capita income causing propensity to consume more livestock products (Lee and Lee, 2003), which in turn has led to increase greenhouse gas (GHG) emissions from livestock agriculture. In 2009, the government of Korea announced the reduction of GHG emissions up to 30% nationwide and 5.2% in livestock agriculture with active application of reduction methods, compared to GHG emissions estimated by Business-as-Usual in 2020. Key categories and emissions of GHG sources should be examined accurately in order to accomplish the GHG reduction target (Kim, 2007).

According to the revised 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories, methane (CH_4) and nitrous oxide (N_2O) are the target gases in livestock agriculture. Enteric fermentation is the source of CH_4 and manure treatment is the source of CH_4 and N_2O. Methane from enteric fermentation is the byproduct of microbes' metabolic activities in the digestive organs. Microbes in anaerobic rumen, especially, play a key role in digesting feed for ruminant, which causes higher CH_4 production compared to pseudo-ruminant and monogastric livestock. Methane emissions during manure treatment are produced by microbes digesting organic matters in manure stored in anaerobic condition. Methane production from manure treatment is mainly affected by the amount of stored manure, organic matter contents in manure, and the portion of manure anaerobically decomposed. Nitrous oxide emissions during manure treatment are produced during

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decomposition of nitrogen sources in anoxic condition. Methane and N_2O emissions are also affected by the location of manure treatment facilities in climate region and the duration of manure treatment (Park et al., 2006; 2011).

Quantifying GHG emissions from in regional and national livestock agriculture have been studied worldwide (Zhou et al., 2007; Aljaloud et al., 2011; Merino et al., 2011). Previous researches on GHG emissions from livestock agriculture in Korea have been focused on the quantifying CH_4 emission during enteric fermentation for national inventory for CH_4 (Lee and Lee, 2003), the evaluation of GHG emissions during main processes in public livestock manure treatment facilities (Lim et al., 2011), and the evaluation of GHG emissions from livestock manure and food waste co-digesting biogas facility with the life cycle assessment (Nam et al., 2008). Currently local administrative districts are interested in the characteristics of their GHG emissions and GHG mitigation measures. Hence, this study was conducted to determine the characteristics of CH_4 and N_2O emissions from livestock agriculture and to estimate those emissions in the past and in the future in 16 local administrative districts.

MATERIALS AND METHODS

Activity data and system boundary

Activity data and emission factors in livestock category are essential to calculate GHG emission presented by IPCC (2006). The necessary activity data needed to calculate GHG emission were found in national statistics of the year. Dairy, beef including Korean native cattle called Hanwoo, swine, chicken, goat, sheep, horse, deer, and duck were chosen for this study. Greenhouse gases were emitted by two paths, enteric fermentation and manure treatment. Methane was emitted from enteric fermentation and manure treatment, and nitrous oxide was emitted from manure treatment. It is noteworthy that the populations of goat, sheep, horse, deer, and duck between 1990 and 1992 were not found so that emissions were not calculated. Population of livestock was based on December of the year and shown in Table 1. Activity data of the distribution and the types of livestock manure treatment systems in GIR (2011) were used for 16 local administrative districts of Korea. National mean air temperature (14°C) were used for the mean temperature where manure treatment systems located.

Calculation of greenhouse gas emissions from 16 local administrative districts in Korea

IPCC (2006) guideline was used to calculate GHG emissions. IPCC (1996) and GIR (2011), however, were referred if activity data were not ready for the conditions of IPCC (2006). The conditions of selection of emission factors referred to GIR (2011) are based on Tier 1 approach. According to the explanation of IPCC (2006) guideline and Korea's conditions, emission factors of North America were used for dairy and beef cattle. Emission factors of Western Europe were used for swine. Emission factors of developing countries were used for other livestock. Comparisons of GHG emissions on a CO_2-Eq were estimated using a 100 yr global warming potential of 25 for CH_4 and 298 for N_2O (IPCC, 2006).

In order to forecast GHG emissions from 2010 to 2030, livestock populations were extrapolated with regression calculated by Grapher (2009) based on the livestock population between 1990 and 2009. Maximum limits based on actual population records were, however, set if continuous livestock population increase was anticipated. Correlation analysis was conducted by Matlab (2008) with function command *corrcoef* to find the effects of major livestock species on CH_4 and N_2O emissions in Korea.

RESULTS AND DISCUSSION

Greenhouse gas emissions from 1990 to 2009 in 16 local

Table 1. Population of Major livestock in Korea between year 1990 and 2009

	Beef cattle (head)			Dairy (head)			Swine (head)			Chicken (head)		
	1990	2000	2009	1990	2000	2009	1990	2000	2009	1990	2000	2009
Seoul	248	201	439	572	211	86	2,776	2,034	12	35,167	998	0
Gyeonggi	162,159	148,844	265,871	234,742	204,382	174,191	1,440,611	1,967,773	1,830,041	26,488,670	26,880,825	32,011,008
Incheon	1,163	15,026	19,338	7,892	7,291	3,563	32,913	100,367	46,084	425,914	504,552	808,602
Chungcheongnam	213,643	230,602	343,916	65,800	84,861	83,738	757,363	1,320,661	1,786,094	8,765,832	15,721,716	26,438,696
Daejeon	7,154	4,346	4,737	1,706	293	0	17,125	5,821	2,777	330,515	209,966	90,000
Chungcheongbuk	111,703	111,020	183,081	22,124	29,855	23,396	186,389	392,261	553,852	3,041,583	6,732,073	10,375,922
Jeollabuk	115,966	150,732	305,788	26,549	44,274	33,346	319,891	889,920	1,150,669	5,672,687	13,785,520	20,344,929
Jeollanam	233,539	231,546	439,477	27,883	38,521	30,647	352,662	780,375	830,273	3,774,475	11,242,879	14,002,271
Gwangju	10,162	3,352	6,356	2,778	1,213	605	12,326	11,266	6,733	564,659	203,368	93,000
Gangwon	142,474	106,186	212,362	20,517	24,340	17,468	183,782	357,998	421,307	3,964,021	4,422,762	4,673,274
Gyeongsangbuk	315,677	302,414	510,744	45,341	51,961	39,376	526,327	986,102	1,209,310	11,596,528	14,486,582	20,024,887
Daegu	9,265	16,375	19,562	2,768	5,821	2,781	22,675	38,824	20,612	308,903	293,249	363,600
Gyeongsangnam	259,326	221,540	268,676	40,058	41,739	29,112	547,107	948,462	1,167,616	7,841,607	5,940,335	7,515,661
Busan	1,145	2,022	1,959	1,929	1,293	663	16,869	39,535	14,564	848,514	163,434	89,880
Ulsan	-	24,082	24,207	-	2,096	980	-	37,325	35,689	-	658,475	517,690
Jeju	38,030	21,732	28,192	3,288	5,557	4,696	109,192	335,645	509,270	804,015	1,300,049	1,418,123

Table 2. The CH_4 and N_2O emissions from livestock agriculture in 16 local administrative districts of Korea from 1990 to 2009

	CH_4 emissions from enteric fermentation (t/yr)			CH_4 emissions from manure treatment (t/yr)			N_2O emissions from manure treatment (t/yr)			CO_2-equivalent emissions* (kt/yr)		
	1990	2000	2009	1990	2000	2009	1990	2000	2009	1990	2000	2009
Seoul	87	43	38	58	30	6	1	1	1	3	2	1
Gyeonggi	39,159	35,934	38,130	26,498	29,188	26,515	683	769	817	1,591	1,606	1,611
Incheon	1,066	1,873	1,552	745	1,293	633	15	40	30	43	79	55
Chungcheongnam	20,421	24,867	31,242	10,592	16,622	20,838	384	567	767	770	1,047	1,332
Daejeon	611	284	260	258	76	30	11	6	5	22	9	8
Chungcheongbuk	8,877	10,386	13,535	3,031	5,314	6,477	147	225	313	296	399	517
Jeollabuk	9,838	14,983	22,139	4,475	10,531	12,455	188	384	566	359	655	902
Jeollanam	16,280	18,656	28,546	4,899	9,337	9,666	274	429	598	530	721	988
Gwangju	893	351	428	288	181	107	14	8	8	29	14	14
Gangwon	10,309	9,345	14,131	2,970	4,634	4,874	172	195	274	332	354	484
Gyeongsangbuk	23,007	24,135	33,860	7,640	11,947	13,430	413	524	722	772	920	1,217
Daegu	860	1,654	1,417	367	687	363	14	27	23	30	57	44
Gyeongsangnam	19,412	18,650	19,776	7,360	10,749	11,944	355	418	479	672	747	815
Busan	319	329	231	275	414	166	9	11	6	15	19	10
Ulsan	-	1,599	1,481	-	475	394	-	30	29	-	53	48
Jeju	2,577	2,487	3,214	1,163	3,198	4,627	54	94	142	95	149	209
Total	153,716	165,576	209,980	70,619	104,676	112,525	2,734	3,728	4,780	5,559	6,831	8,255
Annual growth rate (%, 1990-2009)		1.7			2.6			3.2			2.2	

* CO_2-equivalent emissions = CH_4 (25) and N_2O (298) according to 2006 IPCC GL.

administrative districts of Korea

Yearly CH_4 and N_2O emissions from 16 local administrative districts of Korea between 1990 and 2009 were calculated and data for 10 yearly emissions are shown in Table 2. Livestock activity data of Ulsan were included in Gyeongsangnam up to 1997 and thereafter were separated as Ulsan from Gyeongsangnam.

Yearly CH_4 emissions from enteric fermentation in the 16 local administrative districts of Korea between 1990 and 2009 increased from 153,717 t in 1990 to 231,271 t in 1996 and then decreased to 157,131 t in 2001 and increased thereafter to 209,978 t in 2009. Methane emissions by enteric fermentation in Gyeonggi, the highest enteric CH_4 emitter among 16 local administrative districts, recorded 44,824 t in 1994 and decreased thereafter. Local administrative districts showing decreased CH_4 emissions in 2009 compared to 1990 were Gyeonggi (-1,029 t, -3%), Gwangju (-465 t, -52%), Daejeon (-351 t, -57%), Busan (-88 t, -28%), and Seoul (-48 t, -57%). Methane emissions from enteric fermentation in other 11 local administrative districts had increased since 1990. Correlation analysis was conducted to find the effects of major livestock species on enteric CH_4 emissions in Korea (Table 3). Correlation of CH_4 from beef cattle to total CH_4 emissions from enteric fermentation was very high (r = 0.977), which was much stronger than dairy (r = 0.120) and swine (r = -0.098). Hence, beef cattle were main contributor of enteric CH_4 emissions from enteric fermentation.

Yearly CH_4 emissions from manure treatment systems in 16 local administrative districts of Korea between 1990 and 2009 steadily increased from 70,620 t in 1990 to 112,525 t in 2009, which was 29%-60% less than yearly CH_4 emissions from enteric fermentation. Methane emissions by manure treatment systems in Gyeonggi, the highest CH_4 source of manure treatment systems among 16 local administrative districts, were between 26,281 t and 30,767 t from 1990 and 2009. Local administrative districts where emitted less CH_4 from manure treatment systems in 2009 than in 1990 were Daejeon (-227 t, -88%), Gwangju (-181 t, -63%), Incheon (-112 t, -15%), Busan (-108 t, -40%), Seoul (-51 t, -90%), and Daegu (-4 t, -1%). Other 10 local administrative districts emitted steady or more CH_4 (0%-298%) in 2009 than in 1990 from manure treatment systems.

Table 3. Correlation analysis between major livestock species and CH_4 and N_2O emissions of livestock categories in Korea from 1990 to 2009

	Enteric CH_4	Manure related CH_4	Manure related N_2O	Manure related CO_2 equivalent
Beef cattle	0.977	-0.119	0.604	0.143
Dairy	0.120	-0.328	-0.295	-0.376
Swine	-0.098	0.990	0.693	0.954
Chicken	NE*	0.861	0.700	0.880
Duck	NE	0.923	0.701	0.918

* NE = Not estimated according to IPCC (2006).

Yearly N_2O emissions from manure treatment systems in 16 local administrative districts of Korea between 1990 and 2009 increased from 2,734 t in 1990 to 4,359 t in 1997 and then decreased to 3,691 t in 2001 and increased thereafter to 4,780 t in 2009. When compared to N_2O emissions from manure treatment systems in 1990, N_2O emissions from manure treatment systems in 2009 decreased in Deajeon (-6 t, -58%), Gwangju (-6 t, -42%), Busan (-2 t, -29%) and Seoul (-0.6 t, -53%). Total decreased CH_4 emissions of these 4 local administrative districts were, however, only 16 t. Other 12 local administrative districts emitted 2,062 t more N_2O in 2009 than in 1990. The decreased N_2O emissions were only 0.7% of the increased N_2O emissions, which made the decrease insignificant. With conversion of CH_4 and N_2O emissions from manure treatment systems to carbon dioxide equivalent emission (CO_2-Eq), CO_2-Eq increased from 5,559 kt in 1990 to 8,120 kt in 1996 and then decreased to 6,733 kt in 2001 and increased thereafter to 8,254 kt in 2009.

Correlation analysis was conducted to examine the effects of major livestock species on CH_4 and N_2O emissions from manure treatment systems in Korea. Correlations of CH_4 emissions from manure treatment system of swine, duck, and chicken to total CH_4 emissions were high ($r = 0.990$, $r = 0.923$, and $r = 0.861$, respectively), which were much stronger than dairy ($r = -0.328$) and beef cattle ($r = -0.119$). Hence, monogastric livestock was the main contributor of CH_4 emissions from manure treatment systems. Correlation coefficients of N_2O emissions from beef cattle, dairy, swine, chicken, and duck to total N_2O emissions from manure treatment systems were $r = 0.604$, $r = -0.295$, $r = 0.693$, $r = 0.700$, and $r = 0.701$, respectively. Hence, major livestock except for dairy had moderate correlation with total N_2O emissions. With conversion of CH_4 and N_2O emissions from manure treatment systems to CO_2-Eq, correlation coefficient of CO_2-Eq from swine, duck, and chicken to total CO_2-Eq emissions from manure treatment systems were $r = 0.954$, $r = 0.918$, and $r = 0.880$, respectively, which were much stronger than dairy ($r = -0.376$) and beef cattle ($r = 0.143$). Hence, monogastric livestock were main contributor of GHG emissions from manure treatment systems.

Annual growth rates of enteric CH_4 emissions, CH_4 and N_2O emissions from manure management in Korea from 1990 to 2009 were 1.7%, 2.6%, and 3.2%, respectively. The annual growth rate of total CO_2-Eq was 2.2%. In Korea, annual population growth rate of beef cattle, swine, chicken and duck were 2.6%, 4.0%, 3.3% and 16.0%, respectively, while annual dairy population growth rate was -0.7%. Zhou et al. (2007) reported that annual growth rates of enteric CH_4 emissions, CH_4 and N_2O emissions from manure management in China from 1949 to 2003 were 2.2%, 3.5%, and 3.0%, respectively. The annual growth rate of total CO_2-Eq was 2.4%. They found swine was the main contributor of GHG emissions followed by goat and sheep.

Forecasted greenhouse gas emissions from 2010 to 2030 in 16 local administrative districts of Korea

Yearly CH_4 and N_2O emissions from 16 local administrative districts of Korea between 2010 and 2030 were forecasted and every 10 yr emission data are shown in Table 4. Yearly CH_4 emissions from enteric fermentation in 16 local administrative districts of Korea between 2010 and 2030 were forecasted to increase steadily from 218,906 t in 2010 to 254,987 t in 2030. When compared to CH_4 emissions from enteric fermentation in 2010, CH_4 emissions

Table 4. The forecasted CH_4 and N_2O emissions from livestock agriculture in 16 local administrative districts of Korea from 2010 to 2030

	CH_4 emissions from enteric fermentation (t/yr)			CH_4 emissions from manure treatment (t/yr)			N_2O emissions from manure treatment (t/yr)			CO_2-equivalent emissions* (kt/yr)		
	2010	2020	2030	2010	2020	2030	2010	2020	2030	2010	2020	2030
Seoul	39	35	34	26	25	26	1	1	1	2	2	2
Gyeonggi	38,301	35,778	31,376	30,640	28,874	26,970	861	848	809	1,715	1,620	1,476
Incheon	1,773	2,190	2,625	1,022	1,060	1,093	39	47	56	71	83	95
Chungcheongnam	31,810	37,104	38,035	21,704	26,573	31,602	780	1,000	1,208	1,366	1,647	1,837
Daejeon	214	138	64	29	21	16	4	3	1	6	4	2
Chungcheongbuk	13,656	15,694	15,783	6,559	7,267	7,822	312	373	410	521	598	623
Jeollabuk	23,150	26,083	26,509	12,765	15,312	17,601	574	717	842	932	1,092	1,187
Jeollanam	29,639	33,949	34,101	10,647	11,713	12,493	656	765	815	1,049	1,196	1,231
Gwangju	398	520	654	118	92	74	8	10	11	13	16	19
Gangwon	14,751	16,984	17,192	5,643	6,966	8,256	290	347	378	518	611	651
Gyeongsangbuk	36,797	40,418	40,862	14,628	17,896	21,177	769	911	1,021	1,318	1,507	1,619
Daegu	1,643	1,944	2,244	579	612	639	26	31	35	55	63	71
Gyeongsangnam	21,211	28,139	35,139	13,091	16,175	19,293	514	671	832	880	1,139	1,401
Busan	265	333	436	159	111	84	7	10	14	11	12	15
Ulsan	1,589	2,033	2,485	513	524	535	32	39	46	54	66	78
Jeju	3,669	5,446	7,449	4,887	6,692	8,505	159	240	334	229	329	439
Total	218,905	246,788	254,988	123,010	139,913	156,186	5,032	6,013	6,813	8,740	9,985	10,746

* CO_2-equivalent emissions = CH_4 (25) and N_2O (298) according to 2006 IPCC GL.

from enteric fermentation in 2030 would decrease in Gyeonggi (-6,925 t, -18%), Daejeon (-150 t, -70%), and Seoul (-5 t, -13%). Methane emissions from enteric fermentation in other 13 local administrative districts would increase between 171 t and 13,929 t (11%-103%). The largest increase in CH_4 emissions from enteric fermentation would happen in Gyeonsangnam (13,929 t, 66%).

Methane emissions from manure treatment systems in 16 local administrative districts of Korea between 2010 and 2030 were forecasted to increase from 123,010 t in 2010 to 156,185 t in 2030, which was 95,896 t-111,775 t (39%-46%) less than those from enteric fermentation. When compared to CH_4 emissions from manure treatment systems in 2010, CH_4 emissions from manure treatment systems in 2030 would decrease in Gyeonggi (-3,670 t, -12%), Busan (-75 t, -47%), Gwangju (-44 t, -38%), Daejeon (-13 t, -44%), and Seoul (-0.003 t, -0.01%). Methane emissions from manure treatment systems in other 11 local administrative districts would increase between 22 t and 9,898 t (4%-74%). The largest increase in CH_4 emissions from manure treatment systems would happen in Chungcheongnam (9,898 t, 46%).

Nitrous oxide emissions from manure treatment systems in 16 local administrative districts of Korea between 2010 and 2030 were forecasted to increase from 5,034 t in 2010 to 6,814 t in 2030. When compared to N_2O emissions from manure treatment systems in 2010, N_2O emissions from manure treatment systems in 2030 would decrease in Gyeonggi (-52 t, -6%), Daejeoun (-2 t, -63%), and Seoul (-0.004 t, -0.4%). Nitrous oxide emissions from manure treatment systems in other 13 local administrative districts would increase between 3 t and 428 t (24%-110%). The largest increase in N_2O emissions from manure treatment systems would happen in Chungcheongnam (428 t, 55%) as livestock population would increase more than 3 times in 2030 than in 2010. As a result, CO_2-Eq converted from CH_4 and N_2O emissions from enteric fermentation and manure treatment systems would increase from 8,741 kt in 2010 to 10,747 kt in 2030.

Comparison of mean greenhouse gas emissions from 1990 to 2009 and from 2010 to 2030

Comparison of mean GHG emissions from 1990 to 2009 and forecasted GHG emissions from 2010 to 2030 is shown in Figure 1. Mean CH_4 emissions from enteric fermentation between 2010 and 2030 were compared to

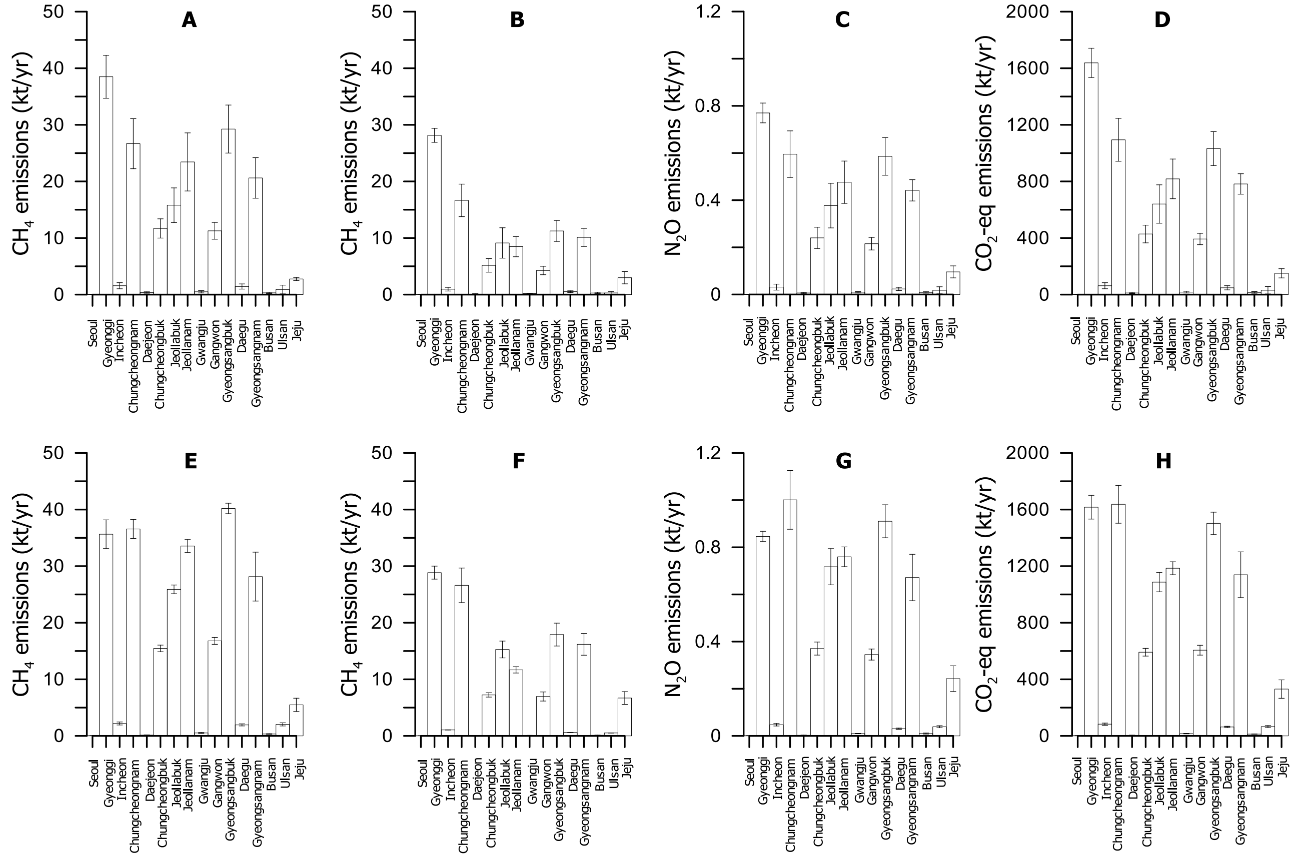

Figure 1. The CH_4 and N_2O emissions from livestock agriculture between 1990 and 2009 are shown in A to D. Forecasted CH_4 and N_2O emissions between 2010 and 2030 are shown in E to H. The average CH_4 emissions from enteric fermentation are shown in A and E. The average CH_4 emissions from manure treatment are shown in B and F. The average N_2O emissions from manure treatment are shown in C and G. The average CO_2-equivalent emissions are shown in D and H. Vertical bars represent standard deviation.

those between 1990 and 2009. Gyeonggi, Daejeon, and Seoul would emit 2,859 t (7%), 232 t (63%), and 20 t (36%) less mean CH_4 emissions from enteric fermentation between 2010 and 2030 than between 1990 and 2009, respectively. While Gyeongsangbuk, Jeollanam and Jeollabuk would emit 10,937 t (37%), 10,103 t (43%), and 10,098 t (64%) more mean CH_4 emissions from enteric fermentation between 2010 and 2030 than between 1990 and 2009, respectively. Other 10 local administrative districts would also emit between 19 t and 9,896 t (4%-114%) more mean CH_4 emissions from enteric fermentation between 2010 and 2030 than between 1990 and 2009. Hence, CH_4 emissions from enteric fermentation should be decreased by adapting low CH_4 emission methods such as feeding low CH_4 generating feed and increasing feed digestibility.

Mean CH_4 emissions from manure treatment systems between 2010 and 2030 were compared to those between 1990 and 2009. Busan, Gwangju, Daejeon and Seoul would emit 173 t (60%), 88 t (48%), 74 t (77%), and 2 t (8%) less mean CH_4 emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009, respectively. While Chungcheongnam, Gyeongsangbuk and Jeollabuk would emit 9,957 t (60%), 6,655 t (59%), and 6,141 t (67%) more mean CH_4 emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009, respectively. Other 9 local administrative districts would also emit between 88 t and 6,073 t (3%-124%) more mean CH_4 emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009.

Mean N_2O emissions from manure treatment systems between 2010 and 2030 were compared to those between 1990 and 2009. Daejeon, Seoul, and Gwangju would emit 4 t (60%), 0.04 t (4%), and 0.02 t (0.2%) less mean N_2O emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009, respectively. While Chungcheongnam, Jeollabuk, and Gyeongsangbuk would emit 406 t (68%), 340 t (90%), and 325 t (55%) more mean N_2O emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009, respectively. Other 10 local administrative districts would also emit between 1 t and 283 t (10%-153%) more mean N_2O emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009. The largest increase of CH_4 and N_2O emissions from manure treatment systems would happen in Chungcheongnam. That was caused by the increase of excreted manure as livestock population forecasted to increase more than 170%. Hence measures to decrease CH_4 and N_2O emissions from manure treatment systems should be prepared.

Mean CO_2-Eq from enteric fermentation and manure treatment systems between 2010 and 2030 were compared to those between 1990 and 2009. Gyeonggi, Daejeon, Busan, Gwangju, and Seoul would emit 22 kt (1%), 8 kt (65%), 3 kt (18%), 1 kt (8%), and 0.5 kt (24%) less mean CO_2-Eq between 2010 and 2030 than between 1990 and 2009, respectively. While Chungcheongnam, Gyeongsangbuk, and Jeollabuk would emit 543 kt (50%), 470 kt (46%), and 447 kt (70%) more mean CO_2-Eq between 2010 and 2030 than between 1990 and 2009, respectively. Other 8 local administrative districts would also emit between 15 kt and 367 kt (31%-120%) more mean CO_2-Eq between 2010 and 2030 than between 1990 and 2009. The decreased CO_2-Eq from 5 local administrative districts were only 34 kt, which was insignificantly small compared to increase of 2,809 kt from other 11 local administrative districts.

Measures to increase accuracy and reliability

The most difficult task to calculate GHG emissions from 16 local administrative districts was to collect activity data, especially manure treatment systems, of 16 local administrative districts. Methane and N_2O emissions from manure treatment systems depended on the location and type of manure treatment systems, and mean temperature where manure treatment systems were located, but it was hard to find official statistical data. Livestock population data was collected by national statistical system, but the high variability made the population forecast difficult.

Uncertainties of activity data such as statistics of livestock population and manure treatment system were obstacles to calculate GHG emissions accurately, so that national approach to improve statistics related to GHG inventory would be key issue. Hence, local administrative districts’ effort on activity data accuracy is essential to improve GHG inventories. In addition, direct measurements of GHG emissions from enteric fermentation and manure treatment systems are indispensable.

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