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$_2$O) 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$_2$O 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$_2$O 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$_2$O 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$_2$O) 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$_2$O. 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...
decomposition of nitrogen sources in anoxic condition. Methane and N<sub>2</sub>O 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<sub>4</sub> emission during enteric fermentation for national inventory for CH<sub>4</sub> (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<sub>4</sub> and N<sub>2</sub>O 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<sub>2</sub>-Eq were estimated using a 100 yr global warming potential of 25 for CH<sub>4</sub> and 298 for N<sub>2</sub>O (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 corrcntf to find the effects of major livestock species on CH<sub>4</sub> and N<sub>2</sub>O emissions in Korea.

**RESULTS AND DISCUSSION**

**Greenhouse gas emissions from 1990 to 2009 in 16 local**

|                  | 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 | 174,491 | 1,440,611 | 1,967,773 | 1,830,041 | 26,488,670 | 26,880,825 | 32,011,008 |
| Incheon          | 1,116 | 15,026 | 13,338 | 7,892 | 7,291 | 3,563 | 32,913 | 234,263 | 146,845 | 23,396 | 3,041,583 | 6,732,073 | 10,375,922 |
| Chungcheongnam   | 213,643 | 230,602 | 343,976 | 65,800 | 84,861 | 83,738 | 757,363 | 1,320,661 | 1,780,049 | 8,765,832 | 15,721,716 | 26,438,696 |
| Daejeon          | 7,154 | 4,346 | 4,737 | 1,706 | 7,291 | 3,563 | 17,125 | 5,821 | 2,777 | 330,515 | 209,968 | 90,000 |
| Chungcheongbuk   | 111,703 | 111,020 | 183,081 | 22,124 | 39,455 | 23,296 | 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 |
| Jeollaam         | 233,539 | 231,546 | 439,477 | 27,883 | 38,521 | 30,647 | 352,662 | 780,375 | 830,273 | 3,774,457 | 11,242,879 | 14,002,271 |
| Gwangju          | 10,162 | 3,352 | 6,356 | 2,788 | 1,213 | 605 | 12,326 | 11,666 | 6,733 | 564,659 | 203,368 | 93,000 |
| Gangwon          | 142,474 | 106,186 | 212,362 | 20,517 | 24,340 | 17,486 | 183,782 | 375,998 | 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 | 1,209,301 | 11,596,328 | 14,486,582 | 20,024,887 |
| Daejeon          | 9,265 | 16,375 | 19,562 | 2,768 | 5,821 | 2,781 | 22,675 | 38,824 | 20,612 | 308,903 | 293,249 | 163,600 |
| Gyeongnamg                     | 259,326 | 221,540 | 266,676 | 40,058 | 41,793 | 29,122 | 547,107 | 498,462 | 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 CH₄ and N₂O emissions from livestock agriculture in 16 local administrative districts of Korea from 1990 to 2009

| Administrative Districts | CH₄ emissions from enteric fermentation (t/yr) | CH₄ emissions from manure treatment (t/yr) | N₂O emissions from manure treatment (t/yr) | CO₂-equivalent emissions* (kt/yr) |
|--------------------------|---------------------------------------------|-------------------------------------------|------------------------------------------|----------------------------------|
|                          | 1990 | 2000 | 2009 | 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    | 1.591  | 1.606  | 1.611 |
| 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 | |
| Gyeonggangbuk            | 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 | 20,650 | 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

* CO₂-equivalent emissions = CH₄ (25) and N₂O (298) according to 2006 IPCC GL.

Table 3. Correlation analysis between major livestock species and CH₄ and N₂O emissions of livestock categories in Korea from 1990 to 2009

| Livestock Species | Enteric CH₄ | Manure related CH₄ | Manure related N₂O | Manure related CO₂ 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\textsubscript{2}O 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\textsubscript{2}O emissions from manure treatment systems in 1990, N\textsubscript{2}O emissions from manure treatment systems in 2009 decreased in Deajeon (-6 t, -58%), Gwangju (-6 t, -42%), Busan (-2 t, -29%) and Seoul (-6 t, -53%). Total decreased CH\textsubscript{4} emissions of these 4 local administrative districts were, however, only 16 t. Other 12 local administrative districts emitted 2,062 t more N\textsubscript{2}O in 2009 than in 1990. The decreased N\textsubscript{2}O emissions were only 0.7% of the increased N\textsubscript{2}O emissions, which made the decrease insignificant. With conversion of CH\textsubscript{4} and N\textsubscript{2}O emissions from manure treatment systems to carbon dioxide equivalent emission (CO\textsubscript{2}-Eq), CO\textsubscript{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\textsubscript{4} and N\textsubscript{2}O emissions from manure treatment systems in Korea. Correlations of CH\textsubscript{4} emissions from manure treatment system of swine, duck, and chicken to total CH\textsubscript{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\textsubscript{4} emissions from manure treatment systems. Correlation coefficients of N\textsubscript{2}O emissions from beef cattle, dairy, swine, chicken, and duck to total N\textsubscript{2}O 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\textsubscript{2}O emissions. With conversion of CH\textsubscript{4} and N\textsubscript{2}O emissions from manure treatment systems to CO\textsubscript{2}-Eq, correlation coefficient of CO\textsubscript{2}-Eq from swine, duck, and chicken to total CO\textsubscript{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\textsubscript{4} emissions, CH\textsubscript{4} and N\textsubscript{2}O 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\textsubscript{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\textsubscript{4} emissions, CH\textsubscript{4} and N\textsubscript{2}O 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\textsubscript{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\textsubscript{4} and N\textsubscript{2}O 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\textsubscript{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\textsubscript{4} emissions from enteric fermentation in 2010, CH\textsubscript{4} emissions

### Table 4. The forecasted CH\textsubscript{4} and N\textsubscript{2}O emissions from livestock agriculture in 16 local administrative districts of Korea from 2010 to 2030

|             | CH\textsubscript{4} emissions from enteric fermentation (t/yr) | CH\textsubscript{4} emissions from manure treatment (t/yr) | N\textsubscript{2}O emissions from manure treatment (t/yr) | CO\textsubscript{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 | 2,625 | 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 |

* CO\textsubscript{2}-equivalent emissions = CH\textsubscript{4} (25) and N\textsubscript{2}O (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 CH₄ 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 39,175 t (39%-46%) less than those from enteric fermentation. When compared to CH₄ emissions from manure treatment systems in 2010, CH₄ 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 CH₄ 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 N₂O emissions from manure treatment systems in 2010, N₂O emissions from manure treatment systems in 2030 would decrease in Gyeonggi (-52 t, -6%), Daejeon (-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 N₂O 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, CO₂-Eq converted from CH₄ and N₂O 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 CH₄ emissions from enteric fermentation between 2010 and 2030 were compared to

![Figure 1](image-url)
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, local administrative districts should be prepared.

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$_2$O 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$_2$O 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$_2$O 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$_2$O emissions from manure treatment systems between 2010 and 2030 than between 1990 and 2009, respectively. The largest increase of CH$_4$ and N$_2$O 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$_2$O 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$_2$O 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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