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Analysis of Greenhouse Gas Emissions Characteristics and Emissions Reduction Measures of Animal Husbandry in Inner Mongolia

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Abstract: Global warming has had a profound impact on human life, with animal husbandry being a significant contributor to greenhouse gas emissions and playing a crucial role in the global greenhouse gas budget. Inner Mongolia is a major contributor to these emissions, making it vital to study the link between greenhouse gas emissions and animal husbandry in this region for the purpose of reducing emissions. In this study, the emissions of greenhouse gases (CH_4, N_2O, and CO_2) from livestock and poultry breeding from 2010 to 2020 and the emissions of each city from 2020 were estimated, the emissions characteristics were analysed, and the low carbon emissions reduction technical measures were proposed. The results show that (1) the overall greenhouse gas emissions from 2010 to 2020 in Inner Mongolia showed a fluctuating trend; the main emissions sources were gastrointestinal fermentation and faecal management. The annual average CH_4 emissions were 994,400 ta^{-1}, and the annual average N_2O emissions were 35,100 ta^{-1}. (2) In 2020, the total emissions of each league city were 38.05 million t equivalent of CO_2, and the emissions gradually decreased from east to west, with a significant emissions reduction potential. Based on these findings, this study also proposed technical measures for reducing carbon emissions, offering theoretical support to drive the industrial transformation and upgrading of the livestock industry, and promoting green economic development in Inner Mongolia as part of its carbon peaking and neutrality goals.

Keywords: animal husbandry; greenhouse gases; emissions reduction

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1. Introduction

The concentration of the CH_4 and N_2O greenhouse gases in the atmosphere increased from approximately 1732 and 270 ppb, respectively, before the Industrial Revolution to 1803 and 324 ppb, respectively, in 2011 [1]. Agricultural activities are the main reason for the sharp increase in greenhouse gas concentrations; the emissions of non-carbon dioxide (N_2O and CH_4) per unit quality of global warming potential (GWP) are 298- and 34-fold that of CO_2 [2–5], such that they have an important contribution to global warming [6–9].

The respiratory metabolism of livestock and poultry, ruminant rumen fermentation, and livestock and poultry manure processing and waste all produce either direct or indirect

CH_4 and N_2O emissions. Animal husbandry has become the main source of agricultural greenhouse gas emissions [10,11]; in the total global greenhouse gas emissions, animal husbandry account for 18%, of which approximately 37% of the CH_4 and 65% of the N_2O derive from animal husbandry [12]. During the 13th Five-Year Plan period (from 2016 to 2020), the number of livestock in Inner Mongolia at the end of the year remained stable at over 70 million, accounting for approximately 9% of the total number of livestock in the country [13]. The size of the livestock inventory is directly related to the greenhouse gas emissions from animal husbandry, which is directly proportional to greenhouse gas emissions [14]. Na et al. [15] estimated the greenhouse gas emissions of livestock and poultry breeding in the Inner Mongolia Autonomous Region from 2007 to 2011. The average annual emissions of N_2O were 14.90 Gg, and the average annual emissions of CH_4 were approximately 758.29 Gg. Among them, intestinal fermentation of livestock and poultry was an important emissions source of CH_4, accounting for 91.86% of the total emissions.

Inner Mongolia is the main animal husbandry breeding site in China and ranks among the highest in the country with regard to the number of livestock and poultry slaughtered each year [16]. By 2020, Inner Mongolia had adopted emissions reduction measures, such as implementing grassland ecological protection and restoration projects; strengthening the treatment of livestock and poultry manure and resource utilization; and promoting natural gas, clean energy, and other technical means to replace traditional coal as energy. However, the implementation effect still remains to be explored. Furthermore, in the current research literature, there are still few studies that estimate the greenhouse gas emissions of livestock and poultry breeding in Inner Mongolia and analyse their emissions laws. In this study, the greenhouse gas emissions characteristics and spatial variation rules of livestock and poultry breeding sources in Inner Mongolia were studied from two aspects: emissions and emissions sources. The study findings contribute towards clarifying the in-depth status of greenhouse gas emissions from livestock and poultry breeding sources in the process of agricultural economic development in Inner Mongolia, with far-reaching significance for saving energy, reducing emissions, and mitigating environmental problems in the region.

2. Methods

2.1. Data Source

We calculated the greenhouse gas emissions of the Inner Mongolia Autonomous Region from 2010 to 2020 for cattle, sheep, pigs, poultry, horses, donkeys, mules, and camels; the activity level data for livestock and poultry; and at the end of the stock using the China Livestock Yearbook, Inner Mongolia Statistical Yearbook, the compilation of agricultural products cost and benefit data, and national data website. We used the calculation method documented in the IPCC (2006) report.

2.2. Direct Calculation of Carbon Emissions from Growth Cycles

The calculation of greenhouse gas emissions from the enteric fermentation of livestock and manure management systems was based on the calculation method adopted by Hu and Wang [17]. The following equations were used for the calculation. CH_4 emissions from the enteric fermentation of livestock were calculated as follows:

$$E_{gt} = \sum_{i=1}^{n} APP_i \cdot ef_{i_1}, \quad (1)$$

where E_{gt} is the CH_4 emissions from the enteric fermentation of livestock, i is the category of livestock, APP_i is the average feeding amount for livestock in the i-th category, and ef_{i1} is the CH_4 emissions factor for the enteric fermentation of livestock in the i-th category. CH_4 emissions from manure management systems were calculated as follows:

$$E_{mc} = \sum_{i=1}^{n} APP_i \cdot ef_{i_2}, \quad (2)$$

where E_{mc} is the CH_4 emissions from the livestock and poultry manure management system, i is the category of livestock and poultry farming, APP_i is the average feeding amount for livestock and poultry in the i-th category, and ef_{i2} is the CH_4 emissions factor for the i-th category of livestock and poultry manure management system. The N_2O emissions from manure management systems were calculated as follows:

$$E_{md} = \sum_{i=1}^{n} APP_i \cdot ef_{i_3}, \quad (3)$$

where E_{md} is the N_2O emissions from the livestock and poultry manure management system, i is the category of livestock and poultry farming, APP_i is the average feeding amount for livestock and poultry in the i-th category, ef_{i3} is the N_2O emissions factor for the i-th category of livestock and poultry manure management system. The CO_2 emissions from livestock and poultry feeding were calculated as follows:

$$E_{ME} = \sum_{i=1}^{n} NAPA_i \cdot \frac{cost_{ie}}{price_e} ef_e + \sum_{i=1}^{n} NAPA_i \cdot \frac{cost_{ic}}{price_c} ef_c, \quad (4)$$

where E_{ME} is the CO_2 emissions from the energy consumption of livestock and poultry production; i is the category of livestock and poultry farming; $NAPA_i$ is the annual production volume of livestock and poultry in the i-th category; $cost_{ie}$ is the electricity consumption per head of livestock and poultry in the i-th category, obtained from the Compilation of Cost Benefit of National Agricultural Products of China; $price_e$ is the unit price of electricity for livestock and poultry farming, obtained from the "Notice on Raising Electricity Prices for North China, Northeast China, Northwest China, East China, Central China, and South China Power Grids" document issued by the National Development and Reform Commission in 2008 (Development and Reform Price (2008) No. 1677, 1678, 1679, 1680, 1681, 1682); the price of agricultural electricity in each province was estimated at an average cost of 0.4275 yuan/kW·h; ef_e is the CO_2 emissions factor of energy consumption from electricity, obtained from the "2012 China Regional Power Grid Baseline Emission Factors" document issued by the National Development and Reform Commission's Department of Climate Change, with the average value of the OM algorithm for the six major regional power grids considered ($ef_e = -0.9734 TCO_2/MW·h$); $cost_{ic}$ is the coal expenditure per head of livestock and poultry in the i-th category, obtained from the 2018 "National Agricultural Costs and Returns Compilation" document; $price_c$ is the unit price of coal used in livestock and poultry breeding (as coal used in farms is mostly used for heating and has no uniform price, estimated at 800 CNY/t); and ef_c is the CO_2 emissions factor of coal consumption, obtained from the "China Energy Statistical Yearbook 2008" and IPCC (Table 1.2, Table 1.4, Chapter 1, Volume II, 2006 in IPCC) documents, where the coal emissions factor was calculated as 1.98 t/t.

2.3. Indirect Carbon Emissions Calculations

Carbon emissions from planting feed grain were calculated as follows:

$$E_{FE} = \sum_{j=1}^{m} \sum_{i=1}^{n} Q_i \cdot t_i \cdot q_j \cdot ef_{ji}, \quad (5)$$

where E_{FE} is the CO_2 emissions from planting feed grain consumed by livestock and poultry; Q_i is the annual output of livestock and poultry products in the i-th category, including pork, beef, mutton, poultry meat, milk, and poultry eggs; t_i is the grain consumption coefficient per unit of livestock and poultry products (data sourced from the "China Rural Statistical Yearbook" and "National Agricultural Costs and Returns Compilation"); and q_j is the proportion of the j-th type of grain in the i-th type of livestock and poultry feed formula, including corn, soybeans, and wheat. Among them, corn accounts for 56.15% of the concentrate feed for pigs, with 37% as cakes, such as soybean cake (14.6% of the concentrate feed for cattle). In the concentrated feed for sheep, corn accounts for 62.61%, and bean and other cakes account for 12.89%, whereas in the concentrated feed for broilers, corn accounts for 57%, wheat accounts for 5%, and bean and other cakes account for 17%. In the concentrated feed for laying hens, corn accounts for 63.28%, and bean and other cakes account for 13.98%. In the concentrated feed for dairy cows, corn accounts for 46.79%, and bean and other cakes account for 28.65%. Here, ef_{ji} is the CO_2 equivalent (CO_2e) emissions coefficient for the j-th type of grain (the emissions coefficient of corn is 1.5, whereas that of wheat is 1.22). As soybean cake is a by-product of soybeans derived after they are first processed and extracted, greenhouse gas emissions from soybean farming are not included in those of animal husbandry.

Carbon emissions from transporting and processing feed grain were calculated as follows:

$$E_{\mathrm{GP}} = \sum_{i=1}^{n} Q_i \cdot t_i \cdot q_j \cdot ef_{ji}, \tag{6}$$

where E_{GP} is the CO_2 emissions produced in the transportation and processing of feed grain consumed by livestock and poultry; Q_i is the annual output of livestock and poultry products in the i-th category, including pork, beef, mutton, poultry meat, milk, and poultry eggs; t_i is the grain consumption coefficient per unit of livestock and poultry products (data sourced from the "China Rural Statistical Yearbook" and "National Agricultural Costs and Returns Compilation"); i is the grain consumption of the i-th category of livestock and poultry products; q_j is the proportion of grains in the j-th type in the feed formula of livestock and poultry in the i-th category, obtained by referring to various livestock and poultry concentrate feed formulas provided by Xie et al. [18]; and ef_{j2} is the CO_2 equivalent emissions factor in the transportation and processing in the j-th category grains. According to data provided in Chapter 3 of the "Livestock's Long Shadow: Environmental Issues and Options" document issued by the Food and Agriculture Organization of the United Nations in 2006, the calculated CO_2 equivalent emissions coefficients in the processing and transportation of corn, soybeans, and wheat used for livestock and poultry feed are 0.0102, 0.1013, and 0.0319 t/t, respectively [19].

Carbon emissions from slaughtering and processing livestock and poultry were calculated as follows:

$$E_{\mathrm{SP}} = \sum_{i=1}^{n} Q_i \cdot \frac{\mathrm{MJ}_i}{e_n} \cdot ef_{\delta}, \tag{7}$$

where E_{SP} is the CO_2 emissions generated during the slaughtering and processing of livestock and poultry; Q_i is the annual output of livestock and poultry products in the i-th category, including pork, beef, mutton, poultry meat, milk, and poultry eggs; MJ_i is the energy consumption per unit of slaughtering and processing of livestock and poultry products, with the energy consumption coefficients for the slaughtering and processing of pork, beef, mutton, poultry meat, milk, and poultry eggs at 3.76, 4.37, 10.4, 2.59, 1.12, and 8.16 MJ/kg, respectively; e_n is the calorific value of 1 degree of electricity (e_n = 3.6 MJ); and ef_{δ} is the CO_2 emissions factor of energy consumption from electricity, obtained by referring to the "2012 China Regional Power Grid Baseline Emission Factors" document issued by the National Development and Reform Commission's Department of Climate Change, with the average value of the OM algorithm for the six major regional power grids considered ($ef_{\delta} = -0.9734\mathrm{TCO_2/MW{\cdot}h}$).

2.4. Total Emissions

Calculated in terms of the CO_2 equivalent, the equation for calculating the greenhouse gas emissions throughout the life cycle of China's animal husbandry industry is as follows:

$$\begin{aligned} E_{Total} &= E_{GT} + E_{CD} + E_{ME} + E_{FE} + E_{GP} + E_{SP} \\ &= E_{gt} \cdot GWP_{CH_4} + E_{mc} + GWP_{CH_4} + E_{md} + GWP_{N_2O} + E_{ME} + E_{FE} + E_{GP} + E_{SP}, \end{aligned} \tag{8}$$

where E_{Total} is the total greenhouse gas emissions in the entire life cycle of animal husbandry calculated as the CO_2 equivalent; E_{GT} is the CO_2 equivalent emissions from the enteric fermentation of livestock; E_{CD} is the CO_2 equivalent emissions from the livestock and poultry manure management systems; E_{gt} is the CH_4 emissions from the enteric fermentation of livestock; E_{mc} is the CH_4 emissions from the livestock and poultry manure management system; E_{md} is the N_2O emissions from the livestock and poultry manure management system; E_{ME} is the CO_2 emissions from the energy consumption for livestock and poultry production; E_{FE} is the CO_2 emissions from feed grains consumed in livestock and poultry production; E_{GP} is the CO_2 emissions generated in the process of feed grain processing and transportation; E_{sp} is the CO_2 emissions generated in the slaughtering and processing of livestock and poultry; GWP_{CH4} is the global warming potential of CH_4, assumed to be 21; and GW_{N2O} is the global warming potential of N_2O, assumed to be 310.

3. Results and Discussion

3.1. Analysis of Livestock and Poultry Breeding and Greenhouse Gas Emissions in Inner Mongolia from 2010 to 2020

The number of livestock and poultry bred in the Inner Mongolia Autonomous Region from 2010 to 2020 is listed in Table 1. The annual average number of livestock was 179.8449 million heads·a^{-1}, with the main types of livestock and poultry in the region being sheep, cattle, live poultry, and pigs; the breeding volume of these types was more than 1 million [20]. For more than 10 years, the number of livestock and poultry bred in the entire region exhibited a fluctuating trend (Figure 1). From 2010 to 2013, the total number of livestock and poultry bred showed an increasing trend, with an increase of more than 25.2%. From 2014 to 2020, the total number of livestock and poultry bred fluctuated slightly, ranging from 4.0 to 5.3%. The total number of cattle and sheep, the main ruminant livestock animals, peaked in 2015, accounting for 37.1% of the total number of heads. From 2010 to 2020, the breeding volume of camels and live poultry exhibited an upward trend, and the sheep breeding volume increased by approximately 10.5% (calculated as follows: (2020 breeding volume − 2010 breeding volume)/2010 breeding volume). The breeding volume of camels increased by approximately 70.0%, and that of live poultry increased by approximately 15.4%. In contrast, the amount of feeding for horses and cattle did not change considerably, amounting to approximately 1.7 and 8.0%, respectively. However, the number of pigs, donkeys, and mules exhibited a downward trend. The number of pigs decreased by approximately 18.8%, that of donkeys decreased by approximately 33.4%, and that of mules decreased by approximately 83.6%.

Table 1. Greenhouse gas emissions from livestock and poultry manure under different management methods.

Greenhouse Gas Emission Factor/(kg/(10^{-2} Million Head Per Year))	Biogas Digester	Solid Storage	Dung Storage	Compost Fermentation	Daily Dispersal	Natural Degradation of Grassland
CH_4	13.30	63.20	39.90	6.65	6.65	17.25
N_2O	0.05	1.16	0.65	1.29	0.71	0.82

The total amount of greenhouse gas emissions from animal husbandry in the Inner Mongolia Autonomous Region showed a fluctuating growth trend (Figure 2). CH_4 emissions from animal enteric fermentation in animal husbandry increased from 826,500 tons in 2010 to 883,800 tons in 2020, with an annual average of 846,800 tons, whereas the CH_4 emissions from manure decreased from 153,200 tons in 2010 to 147,100 tons in 2020, with an annual average of 147,700 tons. Lastly, the N_2O emissions from manure increased from 34,300 tons in 2010 to 34,700 tons in 2020, with an annual average of 35,100 tons.

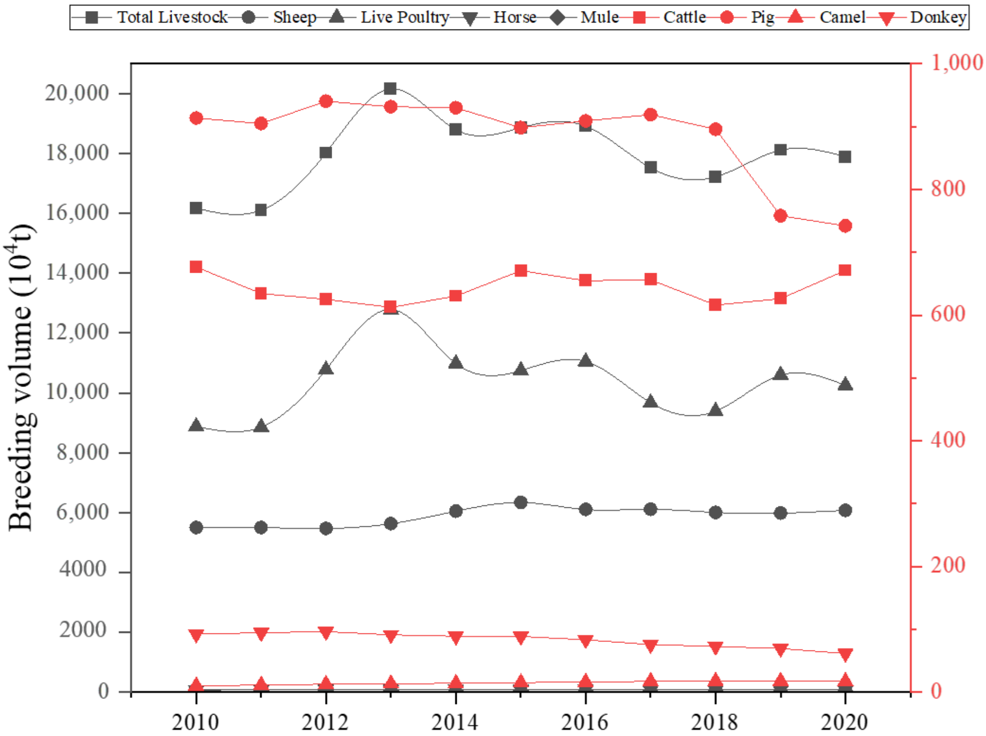

Figure 1. Various types of livestock and poultry bred in Inner Mongolia from 2010 to 2020.

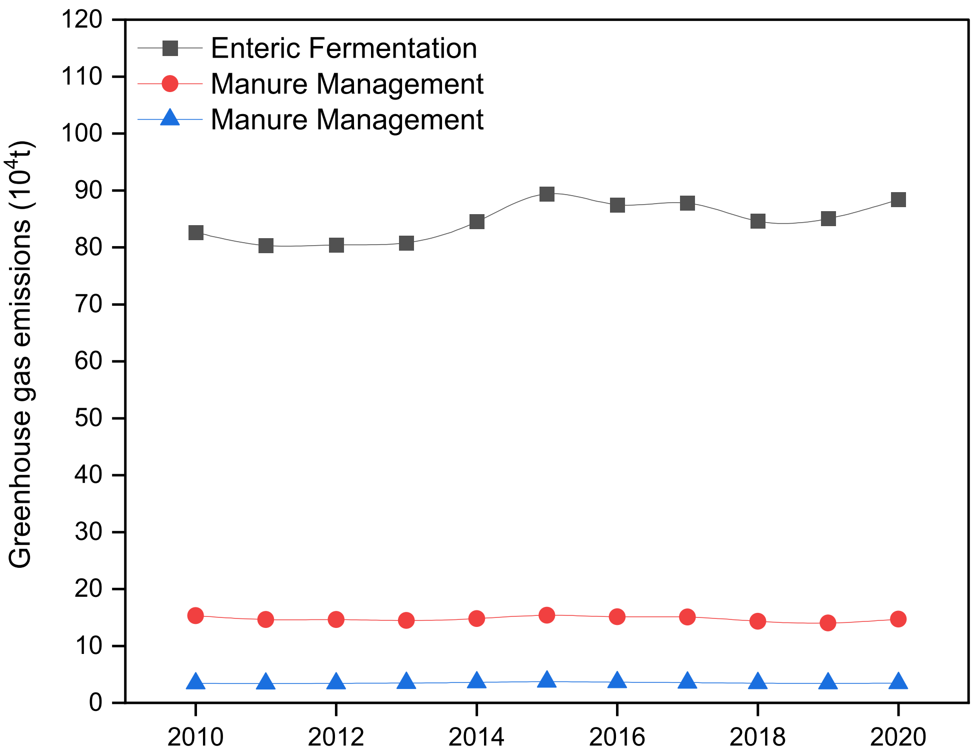

Figure 2. Greenhouse gas emissions from animal husbandry in Inner Mongolia from 2010 to 2020.

Ruminants (cattle and sheep) were the main source of greenhouse gas emissions from animal husbandry in Inner Mongolia, accounting for 78% of the total emissions. Cattle accounted for nearly half of the total greenhouse gas emissions, accounting for 43%, followed by sheep, accounting for 35% of the total. Camels accounted for the third highest emissions, contributing 12% of the total (Figure 3). For the non-carbon dioxide greenhouse gas emissions link in livestock husbandry in Inner Mongolia, the greenhouse gas emissions of livestock husbandry mainly derived from CH_4 in livestock and poultry, accounting for 66%, while the remainder originated from N_2O and CH_4 emissions in the process of manure management, 24 and 10%, respectively (Figure 4). Therefore, the carbon dioxide greenhouse gas emissions should focus on intestinal fermentation of CH_4, such as chopping, crushing, and steam processing during physical processing to improve the digestibility of feed and to reduce the production of ruminant intestinal methane, or by increasing the concentrate feed to improve diet digestibility. For example, the per unit fat protein modified milk can reduce methane emissions by 15%.

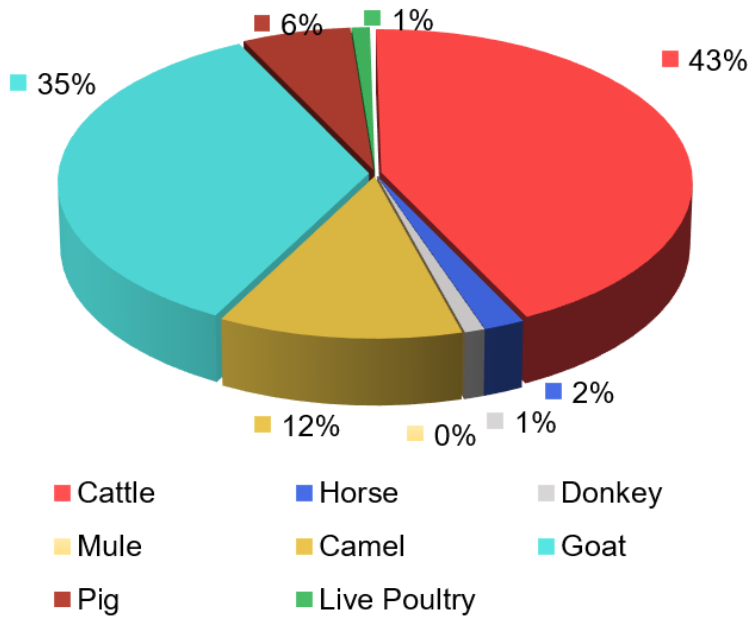

Figure 3. Contribution of livestock to greenhouse gas emissions in Inner Mongolia from 2010 to 2020.

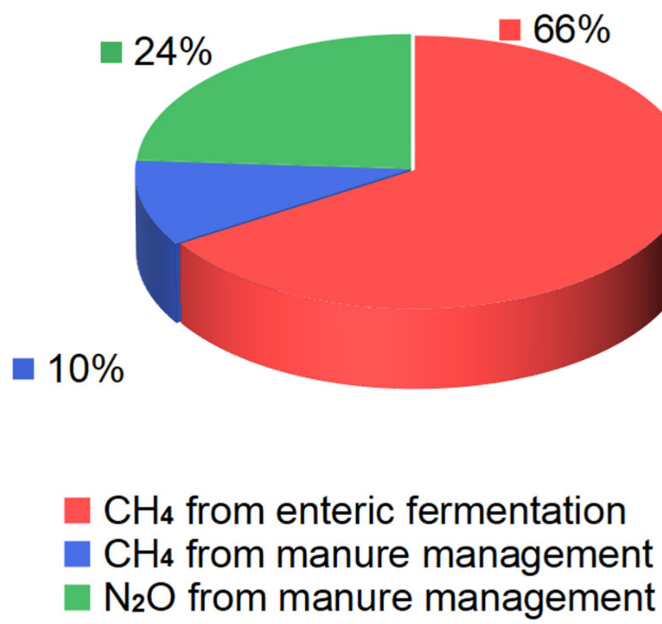

Figure 4. Composition of greenhouse gas emissions sources from animal husbandry in Inner Mongolia from 2010 to 2020.

3.2. Spatial Analysis of Livestock and Poultry Breeding and Greenhouse Gas Emissions in Various Leagues of Inner Mongolia in 2020

As listed in (Figure 5), in 2020, the amount of livestock and poultry breeding in Inner Mongolia was the largest in Chifeng and Bayannur City, with mainly cattle, sheep, and pigs. The number of livestock and poultry in Chifeng city reached 49.4858 million, which was significantly higher than that in other urban areas, accounting for 48.3% of the total amount of the entire Inner Mongolia region. The second is the Xingan League, Tongliao City, and Hulunbuir city, mainly due to the existence of the Hulun Buir grassland and Xilin Gol grassland. Driven by the Horqin beef cattle industry and by the influence of the grain producing area, the amount of cattle breeding in Tongliao city is significantly higher than that in other league cities, reaching 1.9926 million, while the breeding scale in western league cities, such as Alxa League and Wuhai City, is small.

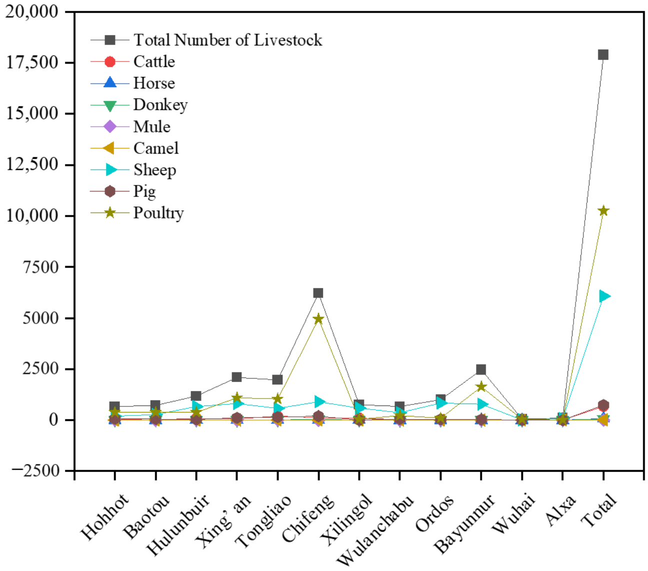

Figure 5. Breeding volume of livestock and poultry in each league of the Inner Mongolia Autonomous Region in 2020.

Non-carbon dioxide greenhouse gas emissions from livestock and poultry are closely related to the structure and scale of livestock and poultry farming. There are large gaps in the greenhouse gas emissions of livestock among different regions in Inner Mongolia. As shown in Figures 6–8, the CH_4 emissions in the eastern region of Inner Mongolia were the largest, accounting for 56.86% of the total, whereas those in the central regions accounted for 29.17%. The western regions accounted for the least CH_4 emissions, accounting for 13.97%. Both CH_4 and N_2O emissions from livestock in the eastern region accounted for more than 50% of the total, and the livestock that emitted more emissions was mainly beef cattle, sheep, goats, dairy cows, pigs, and horses. Therefore, this is the main area of focus for the reduction in and control of greenhouse gas emissions from the breeding industry in the region. The main sources of greenhouse gas emissions from the breeding industry in the central region were dairy cows, sheep, beef cattle, goats, and pigs. Particularly, the dairy industry was dominant in the central region and an important source for emissions reduction. The CH_4 and N_2O emissions from livestock in the western region accounted for less than 15% of the total; therefore, this was the region with the smallest greenhouse gas emissions from livestock in Inner Mongolia. The goat industry is the main industry in this region, and grazing is a dominant practice, which has a large potential for emissions reduction.

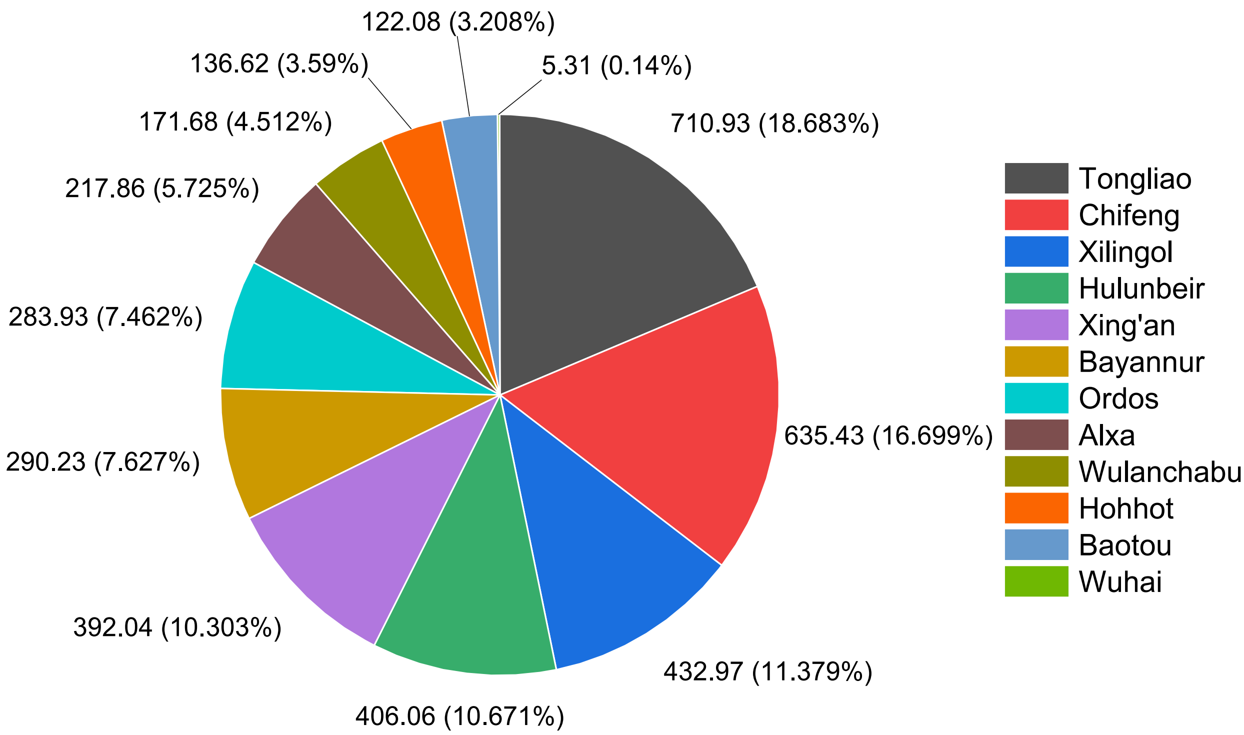

Figure 6. Greenhouse gas emissions from livestock and poultry in the Inner Mongolia Autonomous Region in 2020.

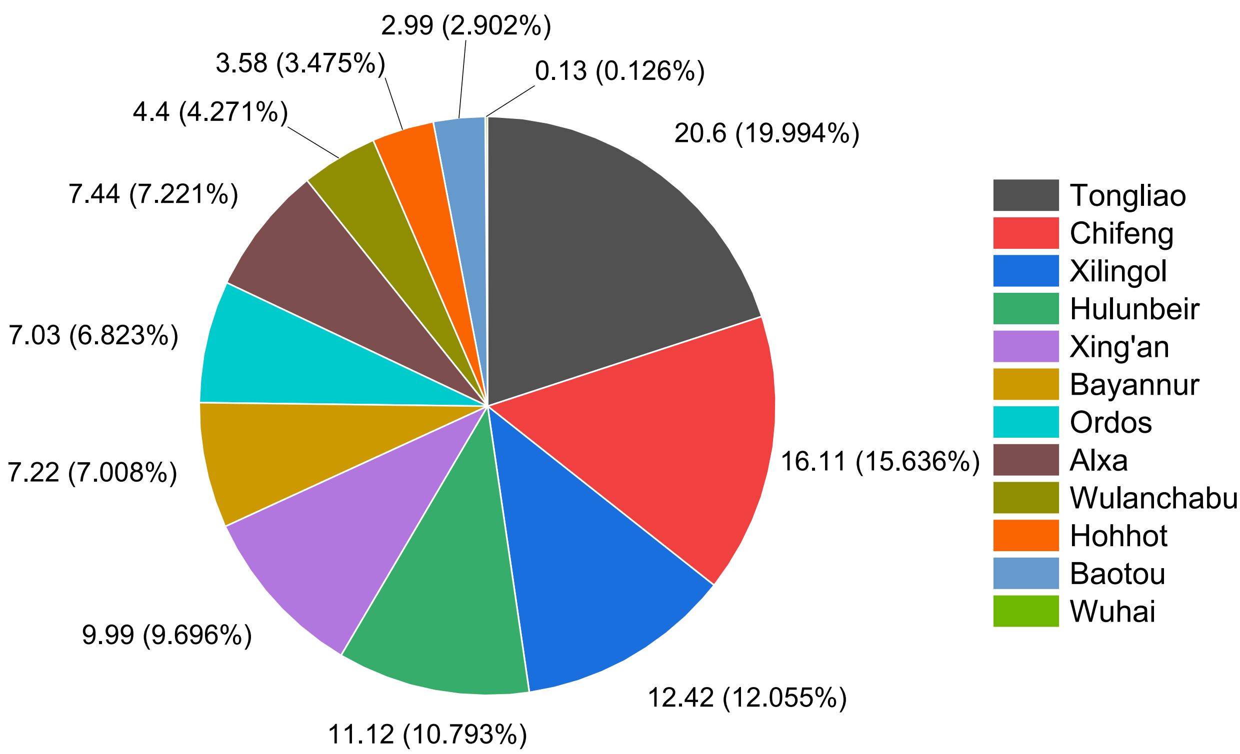

Figure 7. CH_4 emissions from livestock and poultry in Inner Mongolia in 2020.

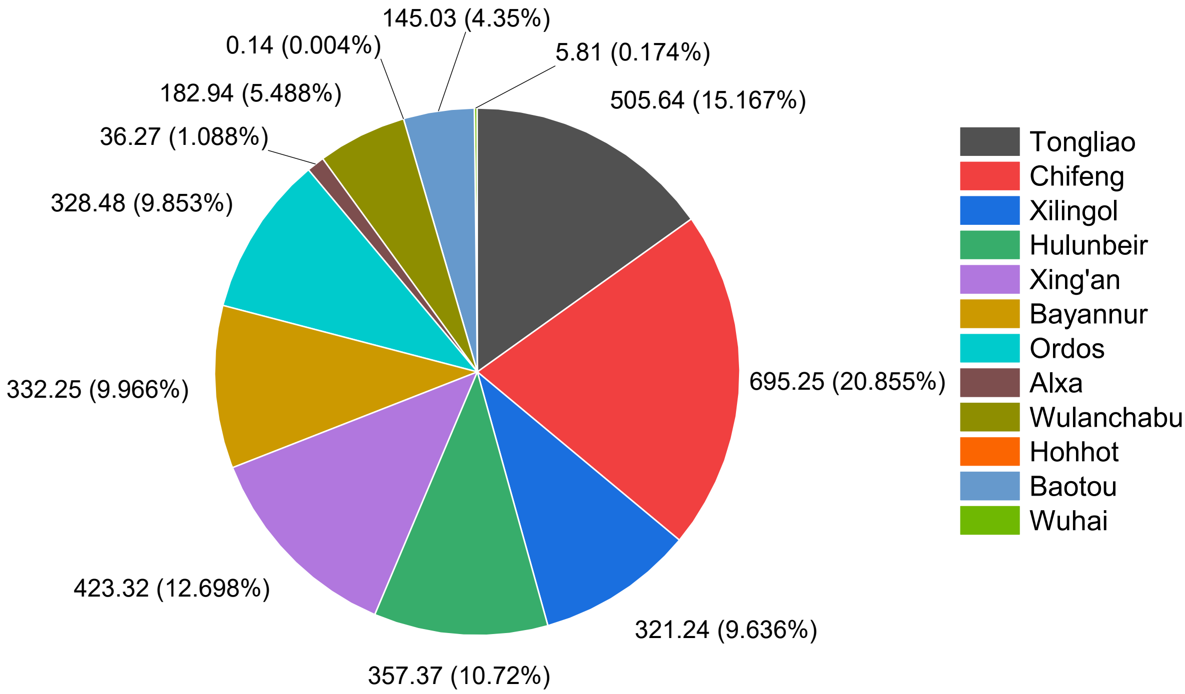

Figure 8. N_2O emissions from livestock and poultry in Inner Mongolia in 2020.

3.3. Analysis of Measures to Reduce Greenhouse Gas Emissions from Animal Husbandry in Inner Mongolia

The number of livestock and poultry is directly related to the potential of greenhouse gas emissions from animal husbandry, with its impact on greenhouse gases, mainly manifesting in the number of animals raised and their feed intake. From 2010 to 2020, the average annual CH_4 emissions from the enteric fermentation of livestock and poultry was 8,468,000 $t{\cdot}a^{-1}$, and cattle and sheep were the main emissions sources, accounting for more than 90% of the total emissions. The greenhouse gas emissions from livestock and poultry farming were consistent with changes in their breeding quantity. In 2015, CH_4 emissions from the enteric fermentation of livestock and poultry increased, largely because the number of ruminant livestock emissions sources, particularly cattle and sheep, was at its highest. The Paris Agreement was ratified in 2015, and China committed to reaching its peak carbon emissions by approximately 2030, prioritising a reduction in greenhouse gas emissions [21–23]. As a result, the total amount of greenhouse gas emissions from animal husbandry in the region declined in the following years.

Pigs are the main emissions source of CH_4 in the process of manure management [24], and pig farming has developed in its intensity and scale over the past 10 years. With the continuous promotion of biogas digester construction projects, the number of scattered farming sites has gradually decreased, resulting in a reduction in emissions [25]. Improved manure management methods can achieve more effective greenhouse gas emission reduction; emissions have exhibited significant differences owing to different management methods (Table 1). Differences in the CH_4 emissions under different management methods were more significant, with the emissions from solid storage at 9.5-fold that of compost fermentation. The N_2O emissions under compost fermentation were 26-fold those of manure management using biogas digesters [26]. This demonstrates that adopting a variety of livestock and poultry manure management methods by considering farming characteristics is a feasible measure to reduce greenhouse gas emissions.

The greenhouse gas emissions level of animal husbandry under intensive and large-scale management is significantly lower than that of free-range farming. Among them, the main body of the implementation measures should include the government, large-scale farmers, and free-range farmers. Therefore, it is the most practical approach for reducing greenhouse gas emissions from animal husbandry. With the government's guidance and support for large-scale farming, as well as the rapid development of modern farming techniques and facilities, the traditional family's free-range breeding model is gradually developing into large-scale farming. By the end of 2017, there were more than 100,000 large-scale livestock and poultry farms in the region, with the scale of livestock and poultry breeding exceeding 70%. Large-scale farming has a significant scale effect in reducing emissions from manure treatment and has better financial conditions to improve the mode of manure management, with biogas digesters viable through its own operating capacity and government subsidies. Building and continuously operating biogas digesters is more challenging for small-scale and decentralised livestock and poultry farming; therefore, in this context, compost decomposition in the field and scattered fertilisation for farmland use is a low-cost and environmentally friendly approach with moderate emissions reduction potential.

Based on the characteristics and existing problems of greenhouse gas emissions in Inner Mongolia, we propose three greenhouse gas emissions reduction strategies suitable for the sustainable development of animal husbandry in Inner Mongolia:

(1) Optimize the structure of animal husbandry, and improve animal production performance, for example, actively adapting to the demand for consumption transformation in the animal husbandry market; promoting the adjustment of livestock and poultry breeding layout; optimizing livestock varieties; promoting the formation of a reasonable layout for industries, such as pigs, poultry, cattle, and sheep; and changing the rumen fermentation mode through the reasonable allocation of daily feed concentrate to the coarse ratio and appropriate use of various feed additives, so as to reduce the emissions of methane from the intestinal fermentation in livestock.

(2) Improve the breeding mode, and promote intensive and large-scale breeding. We should scientifically determine the scale of animal husbandry production and strive to achieve the unity of ecological and economic benefits of animal husbandry production in Inner Mongolia. To develop intensive and large-scale farming, we must shift from traditional farming methods to clean farming methods, improve and implement breeding standards, prevent various diseases, and combine modern microbial fermentation treatment technology to develop ecological fermentation bed farming methods. In contrast, we must cultivate professional and technical talents to scientifically manage animal husbandry, so as to alleviate ecological environmental pollution and help achieve carbon reduction.

(3) Improve the management of manure, and develop circular ecological animal husbandry. One of the main sources of greenhouse gases is the faeces emissions of livestock and poultry. It has become a consensus to develop biogas from livestock and poultry faeces to become an alternative clean fuel. It can be used in conjunction with the construction of solid manure plants, and large- and medium-sized biogas projects for liquid manure, or to collect livestock faeces and to process them into organic fertilizer for the production of livestock and poultry feed in plantations to achieve the organic cycle of agriculture and animal husbandry. This is conducive to significantly reducing greenhouse gas emissions while effectively reducing environmental non-point source pollution.

4. Conclusions and Recommendations

The development of a low-carbon economy has become the current global consensus, and animal husbandry in Inner Mongolia is facing the dual pressure of rapid industrial economic development and greenhouse gas emissions reduction. This study drew the following main conclusions:

(1) The average number of livestock in Inner Mongolia from 2010 to 2020 was 179,844,900 $t \cdot a^{-1}$. The average annual CH_4 emissions from enteric fermentation and manure management was 994,400 $t \cdot a^{-1}$, and the average annual N_2O emissions from manure man-

agement was 35,100 $t \cdot a^{-1}$. In 2020, Inner Mongolia emitted a total of 38.05 million tons equivalent of CO_2, 1.0303 million $t \cdot a^{-1}$ of CH_4, and 33.3374 million $t \cdot a^{-1}$ of N_2O.

(2) CH_4 emissions were the highest in the eastern region of Inner Mongolia (such as Tongliao and Chifeng), with both CH_4 and N_2O emissions from livestock accounting for more than 50% of the total. The dairy industry was dominant in the central region (such as Xilingol) and was a major source of emissions. The western region (such as Alxa and Wuhai) had the lowest greenhouse gas emissions; the goat industry, which is dominated by grazing, was its main industry with a high potential for emissions reduction.

(3) We proposed greenhouse gas emissions reduction strategies conducive to the sustainable development of animal husbandry in Inner Mongolia, providing examples of specific measures from three aspects: livestock breeding structure, breeding mode, and faecal management. Greenhouse gas emissions account for 34% of the manure management process; thus, improving manure management methods and implementing carbon reduction are currently two of the fastest growing measures in animal husbandry. Compared with the other two aspects, the emissions reduction efficiency was higher. Therefore, achieving the recycling of manure resources is the best measure to promote carbon reduction in animal husbandry, which will provide strong support for the sustainable development of animal husbandry.

(4) This study can provide a data basis and theoretical support for the Inner Mongolia Autonomous Region to seek effective emissions reduction measures and can guide the low-carbon development of the livestock and poultry breeding industry.

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