RESEARCH ARTICLE

Influencing mechanism of non-CO$_2$ greenhouse gas emissions and mitigation strategies of livestock sector in developed regions of eastern China: a case study of Jiangsu province

Chuanhe Xiong[1] · Weizhong Su[1] · Hengpeng Li[1] · Zheng Guo[1,2]

Abstract

The livestock sector not only provides people with meat, eggs, milk, and other nutrients but also causes a large number of non-CO$_2$ greenhouse gas emissions. It is urgent to explore the influence mechanism of non-CO$_2$ greenhouse gas emission from the livestock sector and formulate effective mitigation strategies. Taking Jiangsu province as an example, we analyzed the influencing factors of non-CO$_2$ greenhouse gas emissions from the livestock sector based on sources and modified the STIRPAT (stochastic impact by regression on population, affluence, and technology) model, proposed the directions, designed the generally circular path, and determined the focus of non-CO$_2$ greenhouse gas emissions reduction from the livestock sector. The results demonstrated: (1) the top priority of emission reduction of livestock sector in Jiangsu province was the reasonable treatment of manure produced by livestock (non-CO$_2$ greenhouse gas emissions from manure had accounted for more than 60% of the total emissions from the livestock sector since 2007.), and the core was pig manure management (the CH$_4$ and N$_2$O emissions from pig manure accounted for more than 90 and 50% of the total CH$_4$ and N$_2$O emissions from all livestock manure, respectively). (2) The decrease of the agricultural population, the increase of livestock output value per capita of the agricultural population, and the improvement of livestock carbon productivity all reduced non-CO$_2$ greenhouse gas emissions of the livestock sector. For every 1% decrease in agricultural population, for every 1% increase in livestock carbon productivity and livestock output value per capita of the agricultural population, non-CO$_2$ greenhouse gas emissions from the livestock sector would be reduced by 0.0859%, 0.1748%, and 0.0400%, respectively. (3) To construct and improve the low carbon industrial chain of the livestock sector, to promote low carbon technology research and development and introduction are two focuses for non-CO$_2$ greenhouse gas emission reduction in the livestock sector. The research can provide a basis for non-CO$_2$ greenhouse gas emissions reduction from the livestock sector in China, especially in the developed eastern regions.

Keywords Livestock sector · Influence factors · Non-CO$_2$ greenhouse gas emissions · Focuses of emissions reduction · Jiangsu

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Introduction

Since the industrial revolution, greenhouse gas emission has been continuously increasing due to human economic development and social activities, leading to more and more significant climate problems such as global warming (IPCC 2014). Meanwhile, this problem has also become a potential threat to the development of human society and the economy (Carlson et al. 2017; Liao et al. 2021). CO$_2$ emissions are mainly from secondary and tertiary industries, but non-CO$_2$ greenhouse gas emissions (CH$_4$ and N$_2$O) are mainly from agriculture, especially the livestock sector (Xiong et al. 2016; FAO 2016; Cai et al. 2019). It is estimated that, from a

global perspective, CH_4 and N_2O emissions from agriculture account for 50% and 60% of total CH_4 and N_2O emissions due to human activities, and emissions of CH_4 and N_2O from agricultural sources, by 2030, will increase by 60% and 35–60% compared to 2005 levels, respectively (IPCC 2007). Global non-CO_2 greenhouse gas emissions from the livestock sector have reached 19% of the total global greenhouse gas emissions (Reisinger and Clark 2017). Red meat, such as beef and mutton, provides only 1% of the global calories but contributes 25% of total land-use greenhouse gas emissions (Hong et al. 2021). Even if fossil fuel emissions are immediately halted, it is difficult to achieve the 1.5 °C targets according to the current development trends of the food systems (Clark et al. 2020).

Non-CO_2 greenhouse gas emissions from the livestock sector accounted for approximately 30% of the total non-CO_2 greenhouse gas emissions and 54% of the total agricultural greenhouse gas emissions in China. (NCCC 2012). With the improvement of Chinese people's living standards, the consumption demand for animal food will continue to increase (Tilman and Clark 2014; Lin et al. 2015). Non-CO_2 greenhouse gas emission reduction in the livestock sector will become increasingly important, but fortunately, there is a huge potential for non-CO_2 greenhouse gas emission reduction (Havlik et al. 2014; Wang et al. 2014; Gerber et al. 2016; Herrero et al. 2016; Frank et al. 2018; Hong et al. 2021). In 2020, China proposed to achieve a carbon peak by 2030 and strive to achieve carbon neutrality by 2060. There is an urgent need to clarify quantitative targets for non-CO_2 greenhouse gas emission reduction in the livestock sector.

Studies on the influence mechanism of non-CO_2 greenhouse gas emissions in the livestock sector are the key to predicting emission trends and formulating emission reduction strategies. Research on the influence mechanism of non-CO_2 greenhouse gas emissions in the livestock sector has not received much attention. The existing related literature involving the livestock sector of China mainly revealed the regional characteristics (Meng et al. 2014; Luo et al. 2017), decomposed its influencing factors (Tian et al. 2014; Xiong et al. 2016, 2021a; Cai et al. 2018), and explored the differences in non-CO_2 greenhouse gas emissions between different breeding methods and different livestock and poultry products (Xue et al. 2014; Luo et al. 2015; Xu and Lan 2016; Yue et al. 2017; Zhuang et al. 2017). Meng et al. (2014) found that animal husbandry in agricultural areas had higher greenhouse gas emissions but lower emission intensity than animal husbandry in pastoral areas. Xiong et al. (2016) used the LMDI method to decompose the influencing factors of agricultural carbon emissions in Xinjiang and revealed that economic factor was the key promoting factor, while efficiency factor was the main inhibiting factor. Cai et al. (2018) analyzed the factors influencing carbon emission intensity of the

livestock sector in China and found that economic efficiency was the largest contributor to reducing non-CO_2 greenhouse gas emissions of livestock sectors. Luo et al. (2015) showed that household farms were characterized by a higher carbon footprint than that on aggregated farms by research on different breeding methods in Sichuan. Xue et al.'s (2014) study on methane emission inventory of enteric fermentation and manure management of yaks, buffaloes, dairy cows, and beef cattle in China showed that beef cattle were the main source of methane emissions, followed by dairy cows, buffalo, and yaks. Most of the carbon source emission parameters (CO_2 emission parameters of planting industry, such as chemical fertilizer, pesticides, plastic sheeting, diesel, cultivated land, irrigation, etc. CH_4 emission parameters of enteric fermentation and manure from different livestock species and N_2O emission parameters of manure from different livestock species.) in these studies used the IPCC recommended values but did not use the emission parameters that could reflect the regional differences in China. Most of the macro-studies subordinated the livestock sector and the planting sector to agriculture but ignore the particularity of the livestock sector, while the research on the influence mechanism based on LMDI more reflected the decomposition of the driving factors of agriculture; what is more, few related studies used STIRPAT model to identify influencing factors of non-CO_2 greenhouse gas emissions in the livestock sector.

Since the reform and opening up, the economy of Jiangsu province has developed rapidly, and the livestock sector has also flourished. At the same time, it is also an important province for the demand and consumption of livestock and poultry products in China. In this context, Jiangsu's livestock sector faces important challenges in reducing non-CO_2 greenhouse gas emissions. Taking Jiangsu province as an example, we analyzed the influencing factors of non-CO_2 greenhouse gas emissions (CH_4 and N_2O) from the livestock sector based on sources and STIRPAT model, proposed the directions, designed the circular path, and determined the focus of non-CO_2 greenhouse gas emission reduction. The research can provide a basis for non-CO_2 greenhouse gas emissions reduction from the livestock sector in China, especially in the developed eastern regions.

The innovation and contribution of this paper mainly include the following two points. On the one hand, we applied the STIRPAT model to the analysis of the influencing factors of greenhouse gas emissions from the livestock sector, redefined the factors of population, affluence, and technology to adapt to the livestock sector, and identified the influence degree of these factors. On the other hand, combined with the regulation object (included livestock structure, breeding scale, manure management, as well as feed structure and feed treatment) and control means of non-CO_2 greenhouse gas emissions (included population, economy, technology, fund,

market, policy, and diet control), we designed a generally circular path of emission reduction.

Materials and methodology

Calculation of non-CO₂ greenhouse gas emissions of livestock sector

Non-CO₂ greenhouse gas emissions from livestock include CH_4 emissions from enteric fermentation CH_4 and N_2O emissions from manure management. The calculation method is as follows:

$$E_t = E_{CH_4} + E_{N_2O} = \sum N_i \times \alpha_i + \sum N_i \times \beta_i + \sum N_i \times \gamma_i \tag{1}$$

where E_t, E_{CH_4}, and E_{N_2O} represent the total non-CO₂ greenhouse gas emissions, CH_4 emissions, and N_2O emissions. In order to facilitate the standardization, CH_4 and N_2O were converted into CO_2 equivalent (CO₂-eq) according to the heating effect, with conversion coefficients of 25 and 298, respectively (IPCC 2006). N_i represents the annual average feeding amount of species i, and α_i, β_i, and γ_i represent the gastrointestinal methane emission coefficient, manure management methane emission coefficient, and manure management nitrous oxide emission coefficient of species i, respectively. The main breeds of livestock in Jiangsu include nine kinds: dairy cows, beef cattle, goat, sheep, horse, pig, donkey, mule, and poultry. The greenhouse gas emission coefficients of main livestock mainly refer to NDRCC (2013). See supporting information Table S1 for details.

Due to the annual fluctuations in the number of livestock raised during the breeding and slaughtering process, the annual amount of livestock raised needs to be adjusted. The adjustment method is as follows: when the livestock feeding cycle is greater than or equal to 1 year, the year-end stock of the livestock is the annual average feeding amount; when the livestock feeding cycle is less than 1 year, the annual average feeding amount needs to be adjusted according to the annual livestock output and livestock feeding cycle, and the adjustment formula is based on IPCC (2006). The annual feeding amount was calculated by the formula (2). Among the livestock raised, the feeding cycle of pigs and poultry in China in 200 days and 55 days, respectively, (Yao et al. 2017), both of which are less than one year, so they need to be adjusted.

$$N_i = \begin{cases} \text{Herds}_{end} & \text{if} : \text{Days}_{live} \geq 365 \\ \text{Days}_{live} \times \left(\frac{NAPA}{365} \right) & \text{if} : \text{Days}_{live} < 365 \end{cases} \tag{2}$$

where N_i is the annual livestock feeding amount, Herds_end is the year-end stock, Days_live is the livestock feeding cycle, and *NAPA* is the annual livestock output.

Modified STIRPAT model adapt to livestock sector

In this paper, the STIRPAT model is used to analyze the non-proportional effects of the population (P), economy (A), and technology (T) on non-CO₂ greenhouse gas emissions of the livestock sector (I), i.e., $I = aP^b A^c T^d e$. In an econometric analysis, the model will adopt a logarithmic form, which can not only reduce heteroscedasticity but also directly obtain the elasticity of the dependent variable to the independent variable (Xiong et al. 2020a, 2021a). The specific formula is as follows:

$$\ln I = \ln a + b \ln P + c \ln A + d \ln T + \ln e \tag{3}$$

where

(i) *I*, i.e., total non-CO₂ greenhouse gas emissions of the livestock sector. Its unit is tons CO₂-eq.

(ii) *P*, i.e., agricultural population size. Its unit is people.

(iii) *A*, i.e., economic development level of the livestock sector, represents the output value of the livestock sector divided by the agricultural population. Its unit is Yuan RMB per capita.

(iv) *T*, represents the output value of the livestock sector generated by unit non-CO₂ greenhouse gas emission from the livestock sector, i.e., livestock carbon productivity. Its unit is Yuan/tons CO₂-eq.

(v) In Eq. (3), *a* is the coefficient of the model, *b*, *c*, and *d* represent exponents for the independent variables to be estimated, and *e* is the error term of the model.

Data description

The time-series livestock activity data and time-series livestock economic output data of Jiangsu province used in this paper were obtained from the China Rural Statistical Yearbook (1991–2020) and Jiangsu Statistical Yearbook (1991–2020). The economic output data used in this paper are constant 1990 prices.

Empirical results

Analysis of influencing factors based on non-CO₂ greenhouse gas emission sources of livestock sector

Total non-CO₂ greenhouse gas emissions from livestock sector decreased from 6,357,871.27t CO₂-eq in 1990 to 4,096,266.21t CO₂-eq in 2019, with a peak value of 8,938,190.48t CO₂-eq in 1995 and an annual average value of 6,561,209.65t CO₂-eq (Table 1, Fig. 1). From the composition of emissions, CH_4 emissions from enteric fermentation

and its proportion in the total non-CO_2 greenhouse gas emissions from livestock sector showed a decreasing trend, but it was the primary source for most of the time (1990–2009 and 2019). Although CH_4 emissions from manure management decreased, their proportion in total non-CO_2 greenhouse gas emissions from the livestock sector was increasing, and they gradually became the first source (2010–2018). N_2O emissions from manure management increased first and then declined, while the proportion of N_2O emissions in total non-CO_2 greenhouse gas emissions from the livestock sector showed an upward trend (Table 1). From the sources of different livestock, pigs were the largest source of non-CO_2 greenhouse gas emissions in the livestock sector, and their proportion kept increasing. Poultry, cattle, dairy cows, and goats also accounted for high proportions, but the fluctuations were large (Figs. 1 and 2).

CH_4 emissions from enteric fermentation decreased from 3,568,727.45t CO_2-Eq. (56.13%) in 1990 to 1,637,480.27 CO_2-Eq. (39.97%) in 2019, with a peak value of 5,119,918.56t CO_2-eq in 1995 and an annual average value of 3,127,911.48t CO_2-eq (Table 1). From the sources of different livestock, goats were the largest source of CH_4 emissions from enteric fermentation. Cattle, dairy cows, and pigs also accounted for high proportions (Fig. 2).

CH_4 emissions from manure management decreased from 1,618,541.34t CO_2-Eq. (25.46%) in 1990 to 1 1,453,814.71 CO_2-Eq. (35.49%) in 2019, with a peak value of 2,297,399.89t CO_2-eq in 2003 and an annual average value of 2,034,497.66t CO_2-eq (Table 1). From the sources of different livestock, pigs were the largest source of CH_4 emissions in manure management and accounted for an absolute proportion of more than 90% (Fig. 2).

Table 1 Non-CO_2 greenhouse gas emissions of livestock sector in Jiangsu province (t CO_2 equivalent)

Year	CH$_4$ emissions from enteric fermentation	Proportion	CH$_4$ emissions from manure management	Proportion	N$_2$O emissions from manure management	Proportion	Total carbon emissions
1990	3,568,727.45	56.13	1,618,541.34	25.46	1,170,602.49	18.41	6,357,871.27
1991	3,537,612.63	55.75	1,632,564.39	25.73	1,175,494.42	18.52	6,345,671.44
1992	3,700,916.13	55.43	1,720,942.74	25.77	1,254,979.68	18.80	6,676,838.55
1993	4,029,302.95	56.02	1,811,775.31	25.19	1,351,106.69	18.79	7,192,184.94
1994	4,403,466.37	56.04	1,967,255.68	25.04	1,486,854.24	18.92	7,857,576.29
1995	5,119,918.56	57.28	2,141,870.76	23.96	1,676,401.15	18.76	8,938,190.48
1996	3,078,444.90	46.63	2,122,448.26	32.15	1,401,488.02	21.23	6,602,381.18
1997	3,495,768.36	53.57	1,720,911.06	26.37	1,309,141.99	20.06	6,525,821.40
1998	3,719,147.23	52.96	1,926,445.29	27.43	1,377,045.45	19.61	7,022,637.97
1999	3,655,827.23	52.50	1,926,197.43	27.66	1,381,912.50	19.84	6,963,937.15
2000	3,860,234.42	51.66	2,110,232.72	28.24	1,501,466.79	20.09	7,471,933.92
2001	4,047,676.51	51.59	2,217,325.63	28.26	1,580,409.04	20.14	7,845,411.18
2002	4,286,147.91	52.39	2,255,819.73	27.57	1,639,651.46	20.04	8,181,619.10
2003	4,465,047.98	52.92	2,297,399.89	27.23	1,674,853.61	19.85	8,437,301.48
2004	4,440,087.26	52.92	2,283,013.12	27.21	1,666,696.24	19.87	8,389,796.62
2005	4,374,040.55	52.60	2,274,858.86	27.36	1,666,867.31	20.04	8,315,766.71
2006	4,390,196.82	52.67	2,276,298.78	27.31	1,668,193.96	20.02	8,334,689.55
2007	1,953,364.90	39.45	1,818,128.21	36.72	1,180,174.98	23.83	4,951,668.08
2008	2,012,735.92	38.67	1,943,706.19	37.34	1,248,953.92	23.99	5,205,396.04
2009	2,052,342.05	37.91	2,049,266.17	37.85	1,312,325.87	24.24	5,413,934.10
2010	2,092,412.50	37.37	2,129,055.26	38.02	1,378,188.04	24.61	5,599,655.80
2011	2,093,598.97	37.10	2,152,598.94	38.15	1,396,508.03	24.75	5,642,705.95
2012	2,024,940.51	35.32	2,266,232.13	39.53	1,442,334.26	25.16	5,733,506.90
2013	1,999,405.92	35.24	2,262,441.23	39.87	1,412,117.01	24.89	5,673,964.16
2014	2,031,483.60	35.53	2,276,874.85	39.82	1,409,687.75	24.65	5,718,046.20
2015	2,024,861.30	36.10	2,208,497.60	39.38	1,374,933.04	24.52	5,608,291.94
2016	1,967,691.10	36.39	2,114,308.33	39.10	1,324,950.91	24.50	5,406,950.33
2017	1,917,900.07	36.44	2,073,276.02	39.39	1,272,652.67	24.18	5,263,828.76
2018	1,856,564.08	36.67	1,982,829.22	39.17	1,223,052.39	24.16	5,062,445.69
2019	1,637,480.27	39.97	1,453,814.71	35.49	1,004,971.22	24.53	4,096,266.21

Fig. 1 Non-CO$_2$ greenhouse gas emissions of different livestock in Jiangsu province
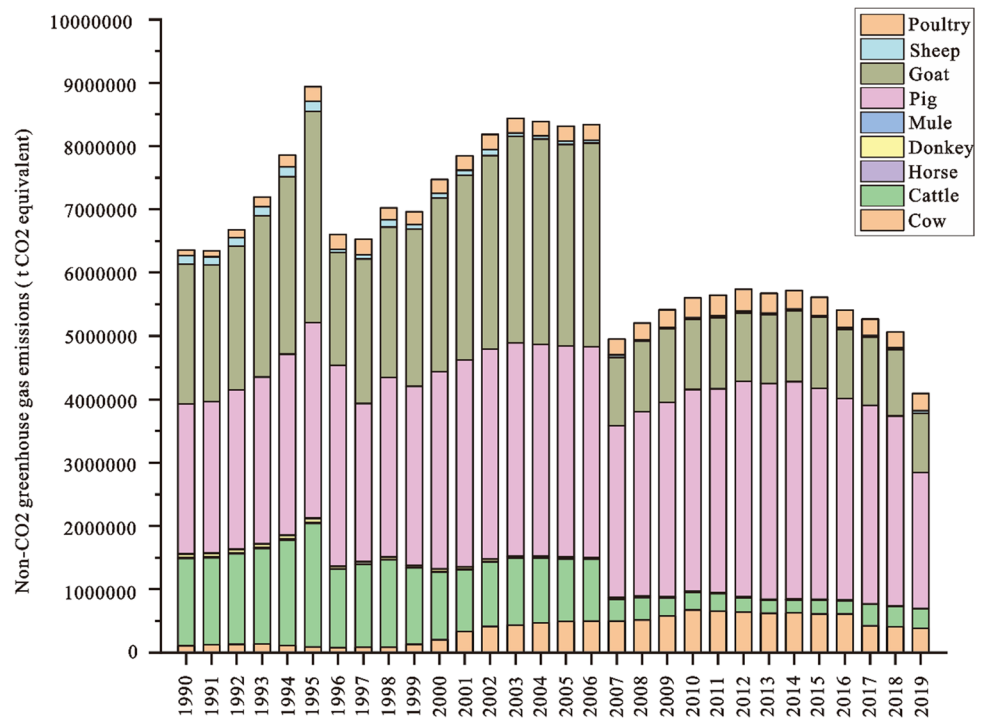
N$_2$O emissions from manure management decreased from 1,170,602.49t CO$_2$-Eq. (18.41%) in 1990 to 1,004,971.22 CO$_2$-Eq. (24.53%) in 2019, and its peak was 1,676,401.15 t CO$_2$-eq in 1995, with an annual average value of 1,398,88.50t CO$_2$-eq (Table 1). From the sources of different livestock, pigs were the largest source of N$_2$O emissions from manure management. Poultry, cattle, dairy, cows, and goats also accounted for high proportions, but with large fluctuations (Fig. 2).

Influencing mechanism of non-CO$_2$ greenhouse gas emissions of livestock sector based on STIRPAT model

The results of multiple regression analysis of the data using SPSS were shown in Table 2. Except for the agricultural population, VIF values of other variables were all greater than 10, indicating that there was serious multicollinearity. In order to eliminate the effect of multicollinearity, the ridge regression method was adopted in this paper to regress the data, and the results were shown in Table 3.

As can be seen from Table 3, ln*P* passed the significance level test of 5%, other variables passed the significance level test of 1%, R^2 was 0.6473, and *F* statistic also passed the significance level test of 1%. Therefore, the STIRPAT model can better explain the relationship between non-CO$_2$ greenhouse gas emissions from the livestock sector and their respective variables in Jiangsu province. The specific formula is as follows:

$$\ln I = 3.2621 + 0.0859\ln P - 0.0400\ln A - 0.1748\ln T \quad (4)$$

According to the coefficient of formula (4), the increase of agricultural population promoted the increase of non-CO$_2$ greenhouse gas emissions from the livestock sector in Jiangsu province. For every 1% increase in agricultural population, non-CO$_2$ greenhouse gas emissions from the livestock sector would increase by 0.0859%. The increase of livestock output value per capita of the agricultural population and the increase of livestock carbon productivity inhibited the increase of non-CO$_2$ greenhouse gas emissions from the livestock sector in Jiangsu Province. The inhibiting effect of livestock carbon productivity was the strongest. For every 1% increase in livestock carbon productivity and livestock output value per capita of the agricultural population, non-CO$_2$ greenhouse gas emissions from the livestock sector would be reduced by 0.1748 and 0.0400%.

Mitigation strategies of non-CO$_2$ greenhouse gas emissions of livestock sector

Directions of non-CO$_2$ greenhouse gas emissions reduction of livestock sector

(1) Orderly nonagricultural development. At the present stage of rapid urbanization in China, the agricultural population mainly affects the non-CO$_2$ greenhouse gas emissions of the livestock sector through the following two aspects. First, with the decrease of the agricultural

Fig. 2 Non-CO$_2$ greenhouse gas emissions structure of different livestock in Jiangsu province. **A** CH$_4$ emissions from enteric fermentation; **B** CH$_4$ emissions from manure management; **C** N$_2$O emissions from manure management; **D** total carbon emissions
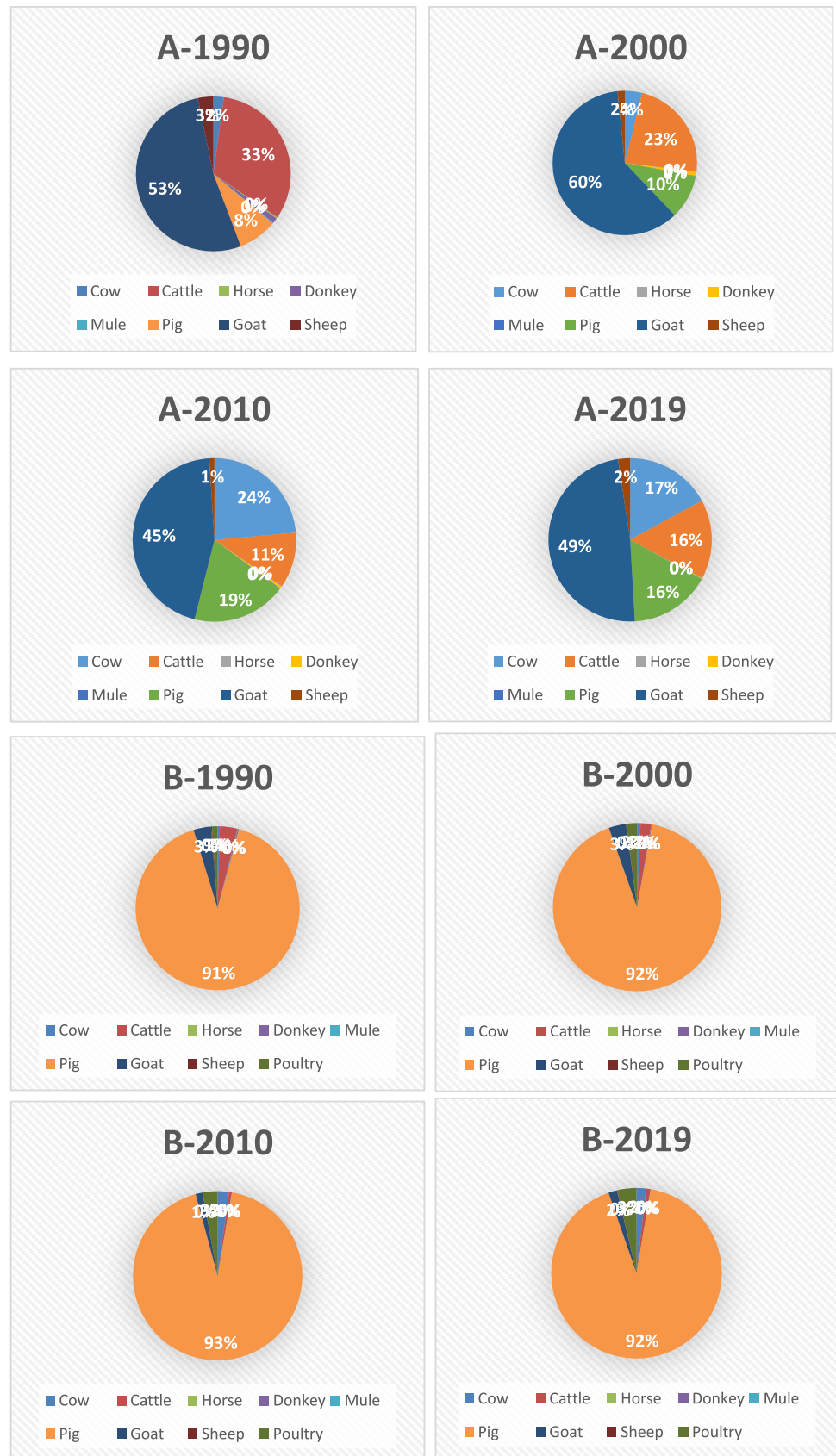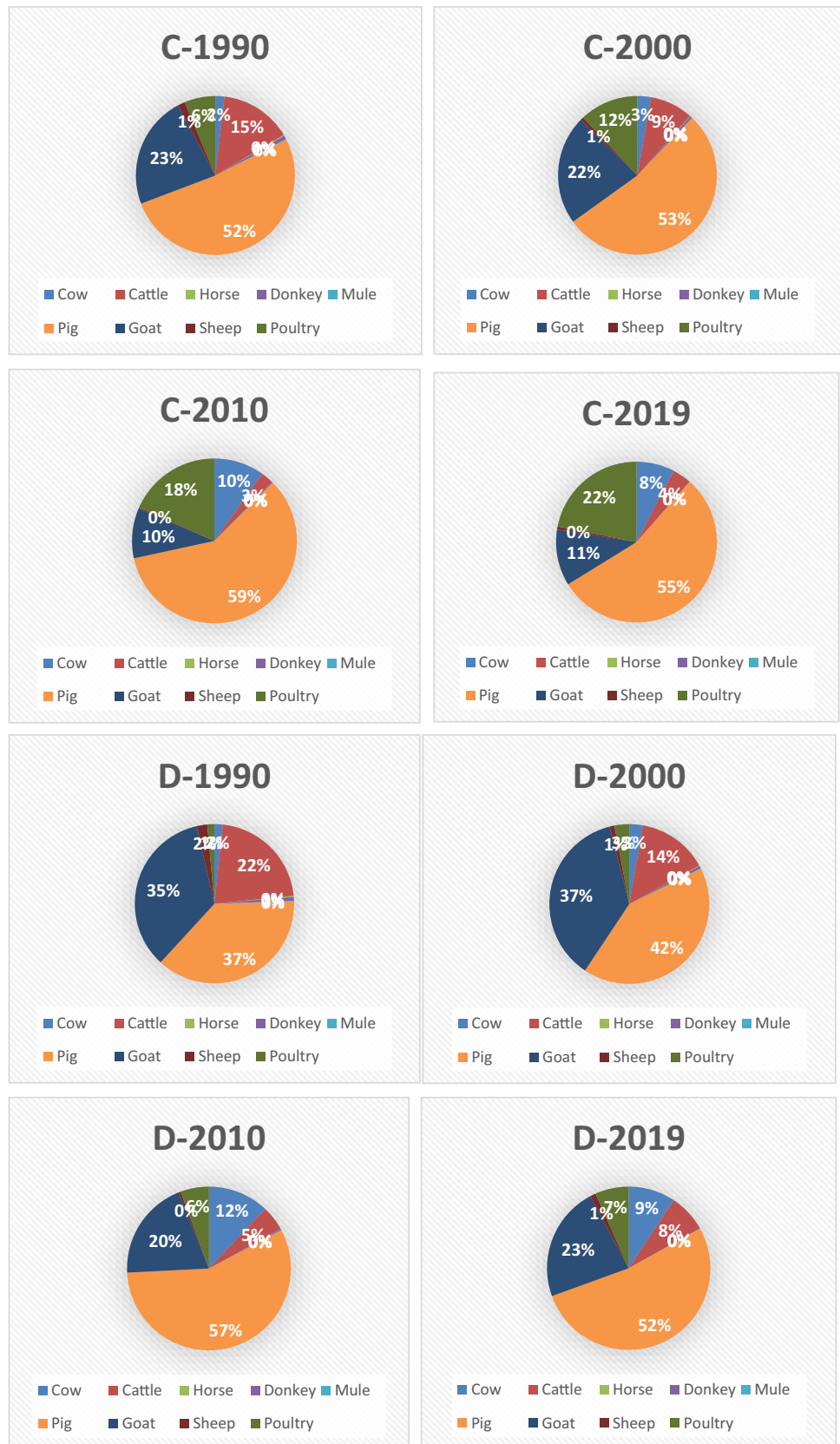
Fig. 2 (continued)

Table 2 Estimate results by ordinary least squares

Variables	Unstandardized coefficients	t-statistic	Sig	Variance inflation factor
C	2.3950	22.1442	0.0000	
$\ln P$	0.9801	32.8547	0.0000	3.2994
$\ln A$	1.0028	93.0165	0.0000	10.5043
$\ln T$	−1.0018	−154.9991	0.0000	11.3737
R^2	0.9994			
F-test	15,253.33			
Sig	0.0000			

Table 3 Estimate results by ridge regression

Variables	Unstandardized coefficients	Standard coefficient	t-statistic	Sig
C	3.2621	0.0000	11.5073	0.0000
$\ln P$	0.0859	0.1184	2.1607	0.0401
$\ln A$	−0.0400	−0.1170	−2.8913	0.0077
$\ln T$	−0.1748	−0.4263	−7.3126	0.0000
K	0.55			
R^2	0.6473			
F-statistic	15.9034			
Sig	0.0000			

population, the extensive operation and management of livestock led to an increase in emissions. The second is that the decline in the agricultural population leads to fewer livestock being raised by households and more livestock being raised on a large scale, thus, reducing emissions. As can be seen from Table 3, the decline of the agricultural population in Jiangsu province resulted in the reduction of emissions. In order to make the development of livestock modernization, it is suggested to carry out the orderly nonagricultural development strategy.

(2) Industrialization development of livestock sector. It can be seen from Table 3 that the increase of livestock output value per capita of the agricultural population had an inhibiting effect, which was the result of the large-scale development of the livestock sector. In order to expand its inhibitory effect, combined with the good economic foundation and social resource conditions in eastern China, we propose to implement standardized production in the whole process of the livestock sector and establish an industrial chain covering all links and processes such as prenatal feed procurement, in-process animal breeding, postpartum animal product processing, preservation, marketing, and waste gas recycling.

We should strive to implement standardized production of low-carbon management in every link and form a closed and controllable traceability circulation system within the livestock sector. It can not only realize low-carbon breeding but also improve the operational efficiency of the livestock sector.

(3) Low carbon technology research and development and introduction. Low-carbon technology plays a positive role in promoting carbon emission reduction in the livestock sector (Xiong et al. 2021b). Both enteric fermentation emission reduction and manure management emission reduction cannot be separated from the support of low-carbon technology. The top priority of emission reduction of livestock sector in Jiangsu province was the reasonable treatment of manure produced by livestock (Table 1), and the core was pig manure management (Fig. 2), so as to achieve the purpose of reducing emissions. In fact, the key to the treatment of manure lies in the input of science and technology and the extensive promotion of scientific and technological achievements, which requires vigorously developing the recycling of livestock waste as the main raw material resources, including the development and reuse of new waste feed, the production of low-carbon fertilizer, and the promotion of biogas as the typical representative of clean energy utilization; science and technology is the primary productivity, and increasing the scientific and technological innovation of livestock waste utilization and actively promoting the efficient utilization technology of livestock waste is also in line with the previous analysis conclusion that livestock carbon productivity plays an important role in emission reduction (Table 3).

Design of a general circular path and identification of regional focus of non-CO₂ greenhouse gas emissions reduction of livestock sector

The following four steps are needed to form a generally circular path of non-CO_2 greenhouse gas emission reduction in the livestock sector:

The first step is to set emission reduction targets based on regional reality.
The second step is to find out the important regulating objects from the sources. According to Table 1, Fig. 1, and Fig. 2, the regulating objects of non-CO_2 greenhouse gas emission reduction in the livestock sector include livestock structure, breeding scale, manure management, as well as feed structure and feed treatment that affect CH_4 emissions from livestock enteric fermentation.
The third step is to clarify the control means. In addition to the population, economy, and technology control

means mentioned above, there are also means of the fund, market, policy, and diet control. Non-CO_2 greenhouse gas emission reduction in the livestock sector cannot be achieved without financial support. Sufficient funds can be absorbed through development funds of the livestock sector, taxation, and the market (development of low-carbon livestock technology CCER) (Xiong et al. 2019). Livestock structure often depends on the supply and demand of livestock products in the market, and the adjustment of livestock structure is transformed into the adjustment of market structure. Government policies play an important role in regulating livestock non-CO_2 greenhouse gas emissions (Xiong et al. 2016), including population policy, industrial structure policy, environmental policy, economic development policy, etc. The influence of healthy diet guidance on carbon emission reduction of animal husbandry cannot be ignored. Due to the excessive intake of animal food, the proportion of people suffering from obesity is also showing an exponential rise, which brings a series of health problems (Chaudhary and Krishna 2019; Song et al. 2019). Healthy diet guidance can not only keep people healthy but also reduce the consumption of animal food, so as to reduce non-CO_2 greenhouse gas emissions from the livestock sector (Behrens et al. 2017; Springmann et al. 2018; Xiong et al. 2020b; Yin et al. 2021).

Finally, a comprehensive evaluation is made by judging the implementation of non-CO_2 greenhouse gas emission reduction in the livestock sector. If the emission reduction target is not achieved, the emission situation of livestock sector will be analyzed again, and the main influencing factors will be adjusted. If the emission reduction target is achieved, a new round of carbon emission reduction process in livestock sector will be initiated. The general circular path of non-CO_2 greenhouse gas emissions reduction of the livestock sector is shown in Fig. 3.

The eastern region of China has a developed economy and has advantages in technology, capital, and human resources. Jiangsu province is located in an economically developed region in eastern China. Combined with a good economic foundation and social resource conditions, there are two focuses for non-CO_2 greenhouse gas emission reduction in the livestock sector:

(1) To further construct and improve the low carbon industrial chain of the livestock sector. Jiangsu should promote standardized production, optimize the industrial structure, and innovate the low-carbon technology system.

(2) Low carbon technology research and development and introduction.

Conclusions

Through analyzing the sources and influence mechanism of non-CO_2 greenhouse gas emissions from the livestock sector in Jiangsu Province, we proposed the directions, designed the circular path, and determined the focus of non-CO_2 greenhouse gas emissions reduction of the livestock sector. The main research conclusions were as follows:

(1) The non-CO_2 greenhouse gas emissions from the livestock sector in Jiangsu province had reached their peak and were decreasing year by year. Total non-CO_2

Fig. 3 The general circular path of non-CO_2 greenhouse gas emissions reduction of livestock sector
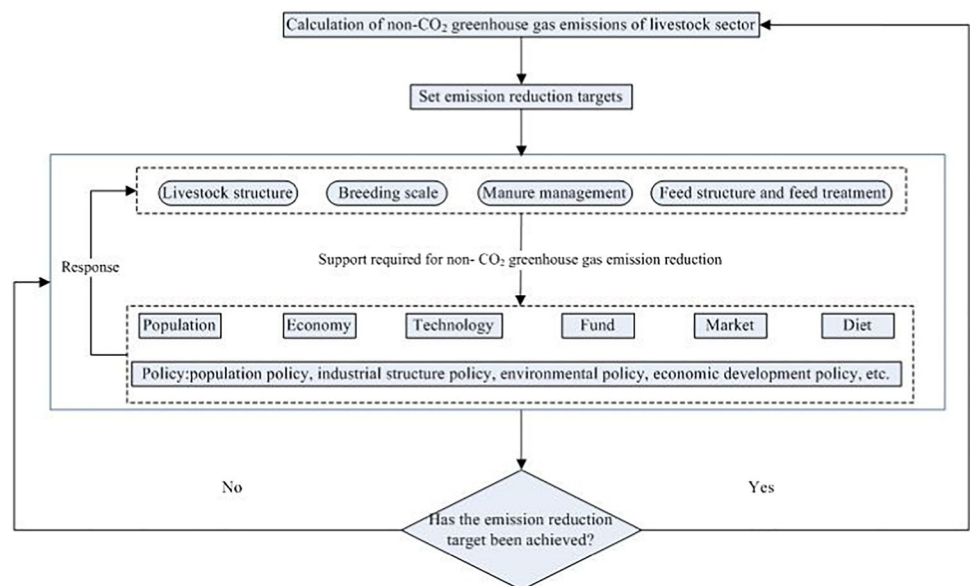
greenhouse gas emissions from the livestock sector decreased from 6,357,871.27t CO_2-eq in 1990 to 4,096,266.21t CO_2-eq in 2019, with a peak value of 8,938,190.48t CO_2-eq in 1995 and an annual average value of 6,561,209.65t CO_2-eq.

(2) The top priority of emission reduction of livestock sector in Jiangsu province was the reasonable treatment of manure produced by livestock, and the core was pig manure management. Non-CO_2 greenhouse gas emissions from manure had accounted for more than 60% of the total emissions from the livestock sector since 2007. The CH_4 and N_2O emissions from pig manure accounted for more than 90 and 50% of the total CH_4 and N_2O emissions from all livestock manure, respectively.

(3) The decrease of agricultural population, the increase of livestock output value per capita of agricultural population, and the improvement of livestock carbon productivity in Jiangsu all reduced non-CO_2 greenhouse gas emissions of livestock sector. For every 1% decrease in agricultural population, for every 1% increase in livestock carbon productivity and livestock output value per capita of the agricultural population, non-CO_2 greenhouse gas emissions from the livestock sector would be reduced by 0.0859%, 0.1748%, and 0.0400%, respectively.

(4) There are two focuses for non-CO_2 greenhouse gas emission reduction in the livestock sector: to construct and improve the low carbon industrial chain of the livestock sector, to promote low carbon technology research and development and introduction.

This study has the following two limitations. On the one hand, this study lacks quantitative research on the fund, market, diet, and other factors mentioned in the generally circular path; On the other hand, it is necessary to supplement the mechanisms and technologies of the livestock sector to realize carbon neutralization, such as carbon sink market mechanism, carbon sequestration technology, etc. Our future researches need to pay special attention to these two aspects.

Author contribution Chuanhe Xiong: data curation, methodology, writing—original draft, and validation. Weizhong Su: writing—reviewing and editing. Hengpeng Li: writing—reviewing and editing. Zheng Guo: investigation.

Declarations

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