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Measurement and Influencing Factors of Carbon Emissions of China's Livestock Husbandry in the Post-COVID-19 Era—Based on the Supply-Side Perspective

Guoming Hao [1], Honghui Zhu [1,*] and Yechen Cui [2]

1 College of Economics and Management, Shihezi University, Shihezi 832003, China
2 School of Engineering Management and Real Estate, Henan University of Economics and Law, Zhengzhou 450046, China
* Correspondence: zhh_jm@shzu.edu.cn

Abstract: The strategy of "carbon peaking and carbon neutrality" and the COVID-19 pandemic have become dual challenges for the high-quality development of livestock husbandry. This paper takes the carbon emissions in China's livestock husbandry as the research object and uses the Intergovernmental Panel on Climate Change (IPCC) Tier 2 coefficient to measure the total carbon emissions and carbon intensity of the industry in 2008–2019. Taking the above two elements as explained variables respectively and using the two-way fixed effects model (FE-TW) that controls time and space effects, this paper specifically examines the effects of various factors in the supply side of livestock husbandry on the explained variables, and further examines the role of technology structure and scale structure. According to our measurement, total carbon emissions showed an inverted U-shaped change and carbon intensity declines in an M-shaped curve during the study period. Both total carbon emissions and carbon intensity are composed mainly of CH_4 that is primarily generated by grass-fed livestock industries with spatial distribution patterns of "hill" and "cliff", respectively, while the spatial expression of these two factors is related to the distribution of grain areas. As the test on supply side factors shows, the carbon emissions of livestock husbandry are apparently affected by its land structure, breeding structure, technical level and scale level, but the impact of the level of human capital and mechanization is not as significant as that of technological structure and scale structure. Combining the empirical results and the special background of the COVID-19 pandemic, this paper aims to provide more targeted suggestions for livestock husbandry development and carbon reduction during the COVID-19 pandemic period. It also aims to offer a reference for the promotion of green and high-quality development of livestock husbandry and the completion of the task of "carbon peaking and carbon neutrality". This study will help policy makers to clarify the goal of reducing carbon emissions in animal husbandry and optimize and improve the corresponding industrial and technological policies.

Keywords: livestock husbandry; total carbon emissions; carbon intensity; supply-side; IPCC Tier 2 coefficients; COVID-19

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1. Introduction

In 2020, President Xi proposed the strategy of "carbon peaking and carbon neutrality", and the State Council required that CO_2 emissions per unit of GDP be lowered by 65% compared with the 2005 level by 2030 [1]. In 2021, the leading group meeting of the above strategies was held, China's national carbon trading market was opened, and the "Work Opinions" on implementing the strategies were released. Despite the impact from the COVID-19 pandemic, the "carbon peaking and carbon neutrality" strategy was launched, which highlighted the high-quality green development of China as a responsible major country. This also reflected China's determination to tackle climate change. Responding to the epidemic and undertaking these strategies are the dual tasks for China in promoting its economic and social development. Globally, the blockade measures adopted by many countries have restricted economic activities, resulting in a 5% year-on-year decrease in CO_2 emissions in 2020. However, such restrictions have not stopped the growth of greenhouse gases. Instead, the growth rate of greenhouse gases exceeds even the annual average of the previous decade, and the total amount has reached a new high [2]. In China, the short-term disruptions of economic activities have significantly reduced carbon emissions. However, with GDP returning to baseline levels, this short-term effect is not enough for the achievement of long-term climate goals. The post-COVID-19 recovery and green transition must focus on "new infrastructure" for sectors such as electricity, steel, cement, transportation, and petrochemicals [3]. However, China's carbon emissions from the agricultural industry account for more than 13% of the country's total, of which nearly 40% comes from livestock husbandry [4,5]. The pandemic has exacerbated the vulnerability of agriculture, and its negative impact on the livestock industry in the agricultural sector is second only to leading enterprises [6,7]. Moreover, during the COVID-19 epidemic, carbon emissions from the food industry and from agriculture increased [8]. Due to its vulnerability and the dual links with both food and agriculture, livestock husbandry has a higher uncertainty in production and carbon emissions. During the economic recovery from the COVID-19 pandemic, while preventing a sharp rebound in industrial carbon emissions, we should pay more attention to carbon emissions from livestock husbandry. In view of this, this paper measures total carbon emissions and carbon intensity of the livestock husbandry and analyzes its influencing factors. It aims to offer some ideas in the promotion of production and reduction of carbon emissions during the recovery of livestock husbandry. Moreover, this paper provides more ideas for the high-quality green development of livestock husbandry to achieve the goal of "carbon peaking and carbon neutrality" in this industry.

2. Literature Review

Total carbon emissions of livestock husbandry are the carbon emissions during the livestock production. Carbon footprint is the carbon emissions generated across the life cycle of the livestock. Comparing studies on EU livestock husbandry, Spanish milk, Canadian pork, and Brazilian cattle, the calculation of a carbon footprint is different from total carbon emissions [9–12]. This is because the calculation of a carbon footprint considers differences in livestock species, regions, scales, and management methods. Moreover, it includes carbon emissions before and after production. After reaching its peak in 2006, the total carbon emissions of livestock husbandry in China have gradually declined. Cattle and pigs contributed the most to these emissions. In other countries, the biggest contributors are cattle, and the other contributors are, in turn, sheep, pigs, and chickens [13–15]. Cattle and pigs have the most CH_4 in their intestines and feces. Total carbon emissions of livestock husbandry in the eastern and western regions follow a "unipolar" pattern, and the central region follows a "gradient" pattern [15]. Sichuan, Henan, and other leading provinces in animal husbandry have high emissions [16]. Moreover, the total carbon emissions in livestock husbandry show obvious spatial and temporal differences in Chongqing, Beijing and Anshun etc. [17–19]. Livestock husbandry creates a lower carbon footprint in livestock intestines or manure, but a higher carbon footprint in links before and after the production, especially links of forage planting, forage transportation, livestock energy consumption, slaughtering, and processing. Spatially, livestock husbandry in farming areas generates a higher carbon footprint than that in pastoral areas, and Western China accounts for the largest proportion. The three largest contributors to the carbon footprint of the Chinese livestock husbandry are the Inner Mongolia Autonomous Region, Liaoning Province, and Yunnan Province [20]. In addition, large-scale livestock farming creates a lower carbon footprint than free-range farming in the case of Sichuan pig farming [21]. In the case of the animal husbandry of the Qinghai–Tibet Plateau, grazing as the method of animal husbandry has a lower footprint than intensive animal farming [22]. In addition, using alfalfa hay, instead of forage concentrate, as animal feed can effectively reduce the carbon footprint, helping China hit the carbon emission peak in advance and significantly reduce the peak emissions [23].

Reducing carbon intensity, which is a specific requirement among the carbon peaking and carbon neutrality goals, influences both the total carbon emissions and the carbon footprint at the macro level. Total carbon emissions and carbon footprint of livestock husbandry in the four major pastoral areas and across the country are negatively related to carbon intensity, followed by agricultural structure. The economic effect of agriculture increases total carbon emissions and the carbon footprint of the livestock husbandry [24,25]. Total population and urbanization have positive and negative effects on the carbon footprint of livestock husbandry, respectively [26]. Similar to carbon intensity, higher efficiency in carbon emission control and larger scale of breeding can reduce the carbon footprint growth of live pigs by half [27]. Besides the production-related factors, other factors that influence carbon emissions include labor prices, land prices, livestock product consumption, and highway density. These factors are negatively correlated with the total carbon emissions of livestock husbandry. Engel coefficient is a positive factor. Urbanization rate is negatively correlated with total carbon emissions of the livestock husbandry of the eastern and central regions, and positively correlated with those in western regions [28]. The carbon footprint of livestock husbandry has a positive relationship with farmers' per capita net income and the disposable income of urban residents [29]. During production, CH_4 emissions are positively correlated with the number of pigs or sheep, and negatively correlated with the number of cattle or camels [30]. Total carbon emissions generated by small pig farming households have a significant negative relationship with the age of the household head, manure disposal methods, and land carrying capacity. Total carbon emissions of medium and large pig farming households are significantly and negatively correlated with the model of "leading enterprises + pig farmers" [31].

To sum up, first, the current literature focuses more on measuring total carbon emissions and the carbon footprint, but less on carbon intensity, which is often treated as an influencing factor on the former. The most direct and effective way to reduce total carbon emissions is to have less livestock. However, as improving technology within a short time is difficult, the solution of keeping less livestock is not enough to "satisfy people's yearning for a better life". The more feasible step is to reduce carbon intensity. When the efficiency is increased, a greater number of livestock can be kept. This method both increases the income of herdsmen and meets people's needs. At the same time, total carbon emissions of livestock husbandry can be controlled to achieve the "emission peak", and finally be reduced to achieve the "carbon neutrality". This method is in line with the idea that "high-quality development means giving priority to ecology and developing in a green way". Secondly, few research has studied factors affecting total carbon emissions. Most of the related studies focus on analyzing macro factors, with only a few concentrating on specific factors. Though specific factors have been studied, these factors do not include those affecting the production of livestock husbandry, but rather those that affect social and economic factors such as market price, income, social development, etc. In livestock husbandry, supply and demand are the determinants of total carbon emissions and carbon intensity, and the direct factor is livestock. Therefore, livestock-related factors are important during production and thus there is a need for comprehensive and in-depth analysis of the supply-side factors, something which would be in line with the requirement of "taking supply-side structural reform as the mainline". Thirdly, although the commonly used life-cycle assessment (LCA) is a comprehensive method to calculate the carbon footprint of livestock husbandry, it produces results with unclear boundaries which cannot be compared. Intergovernmental Panel on Climate Change (IPCC) Tier 1 coefficients are highly comparable because only total emissions during production are estimated, without considering domestic differences. In addition, limited by the particularity of the research subject or data availability, the logarithmic mean index method (LDMI) index is often used to analyze influencing factors, but most of these factors are at macro level, with poor operability. Some studies have used ordinary least squares (OLS) regression. However, such a method assumes no difference in time or space, which may conflict with reality. Finally, the outbreak of Coronavirus has exacerbated the weakness of livestock husbandry and increased the complexity of production recovery. Moreover, the carbon emissions of agriculture and animal husbandry have shown particular patterns during the COVID-19 pandemic. Therefore, it is necessary to place the research in the context of the COVID-19 pandemic.

In conclusion, current research has provided valuable experience and insights for analyzing carbon emissions of livestock husbandry. On this basis, this paper has made the following improvements or innovations. First, it has investigated the carbon emissions of livestock husbandry from both total carbon emissions and carbon intensity and calculated total carbon emissions of livestock husbandry with the Intergovernmental Panel on Climate Change (IPCC) Tier 2 coefficients to derive carbon intensity. Second, it has described the dynamic changes, industrial structure, and spatial distribution of total carbon emissions and carbon intensity of livestock husbandry and analyzed their possible causes. Third, it has used the two-way fixed effects model (FE-TW), which considers time and space effects, to examine impacts from supply-side factors on total carbon emissions and carbon intensity of livestock husbandry. The supply-side factors include land structure, breeding structure, human capital, mechanization, technology, and scale. This is to further examine the impacts from technology structure and scale structure. This paper has combined theory with empirical results to analyze the impact of the COVID-19 on the influencing factors, the production and the carbon emissions in the animal husbandry industry. It aims to provide more targeted suggestions for livestock husbandry development and carbon reduction during the COVID-19 pandemic period and offer a reference for promoting green and high-quality development of livestock husbandry and completing the task of "carbon peaking and carbon neutrality".

3. Measurement of Carbon Emissions of Livestock Husbandry

3.1. Methodology and Indicators of Carbon Emissions of Livestock Husbandry

Carbon emissions from livestock husbandry are calculated by converting all carbon emissions into CO_2 equivalents so that they can be compared. For example, CH_4 is 25 times as potent as CO_2 and N_2O is as many as 310 times more potent [32]. Methods to calculate carbon emissions of the livestock industry include the coefficient method and the carbon footprint method. The coefficient method includes Organization for Economic Cooperation and Development (OECD) coefficients and Intergovernmental Panel on Climate Change (IPCC) coefficients. The carbon footprint method includes Life Cycle Assessment (LCA) and Input–Output method (I-O). As this paper focuses on carbon emissions from livestock production, the coefficient method is adopted. OECD coefficients denote the percentage of feed energy converted to methane by livestock. This coefficient only estimates CH_4 and has a low accuracy, though it was used by a small number of scholars at the end of the last century [33]. IPCC coefficients calculate CH_4 and N_2O emissions from livestock intestines and feces, but the accuracy depends on the levels of the coefficients. The calculation formula of the coefficients in the "2006 IPCC Guidelines for National Greenhouse Gas Inventory" is complex, requiring a lot of information, and some key data are difficult to obtain in China. Therefore, Chinese scholars often refer to the method of Hu et al. to make some adjustments [16]. However, Zhou et al. have pointed out that IPCC Tier 1 coefficients only reflect the average emissions of countries, without considering different conditions of provinces [27]. China spans a large geographic territory, with many provinces of different conditions. Scholars have to adopt different adjustment methods and data for related research. However, this leads to a lack of accuracy, authority or comparability [34]. In comparison, the IPCC Tier 2 coefficients are calculated in accordance with the above-mentioned "Guidelines", which not only consider regional (provincial) differences within a country, but also have more accurate results. The IPCC Tier 2 coefficients used in this paper come from the "2011 Guidelines for the Compilation of Provincial Greenhouse Gas Inventories (Trial)", which was compiled by several units including Tsinghua University under the leadership of the National Development and Reform Commission. The IPCC Tier

2 coefficients consider the fact that there may be no relevant measured data in some places, and so include different recommended values based on livestock species and regions. With transparent and accessible data and consistent format for calculation, the coefficients are accurate, authoritative, and comparable. The formula (Formula 1 is collated from formulas 3.10, 3.12 and 3.14 in the guidelines for the compilation of provincial greenhouse gas inventories (trial)) for calculating total carbon emissions is:

$$C_{p,i,t} = \left[\left(\mathrm{CH_4}_{p,i,enteric} + \mathrm{CH_4}_{p,i,manure} \right) * 25 + \mathrm{N_2O}_{p,i,manure} * 310 \right] * AP_{p,i,t} * 10^{-7} \quad (1)$$

where $C_{p,i,t}$ denotes carbon emissions of the i-th livestock in year t of province p. $\mathrm{CH_4}_{p,i,enteric}$, $\mathrm{CH_4}_{p,i,manure}$ and $\mathrm{N_2O}_{p,i,manure}$ represent the CH_4 emissions coefficient, the CH_4 emissions coefficient of the feces and the N_2O emissions coefficient of the feces of the i-th livestock in p province, respectively. In this paper, these coefficients are the recommended values of the Guidelines. The numbers 25 and 310 are the coefficients for the conversion of CH_4 and N_2O to CO_2, respectively. $AP_{p,i,t}$ is the inventory of livestock of the i-th species in year t of province p. $C_{p,i,t}$ divided by the output value of the i-th livestock species in p province of t year is the carbon intensity of the i-th livestock species in p province of t year, denoted as $C_{intens,p,i,t}$. The units of the above carbon emissions, emissions coefficient, livestock inventory and carbon intensity are 10,000 tons, kg/head, 10,000 heads and 10,000 tons/10,000,000 US dollars respectively. According to $C_{p,i,t}$ and $C_{intens,p,i,t}$, the following indicators can be calculated: $C_{p,t}$ and $C_{intens,p,t}$ represent total carbon emissions and carbon intensity of livestock husbandry in each province each year, respectively. $C_{i,t}$ and $C_{intens,i,t}$ indicate total carbon emissions and carbon intensity of each industry each year, respectively. C_t and $C_{intens,t}$ denote total carbon emissions and carbon intensity of the livestock husbandry in China each year, respectively. Due to a lack of data in Tibet, Hong Kong, Macau, and Taiwan, this paper uses data and output values of the other 30 provinces in the period 2008–2019. These data come from the 2009–2020 "China Livestock Husbandry and Veterinary Yearbook".

3.2. Measurement Results of Carbon Emissions of Livestock Husbandry

3.2.1. Dynamic Changes of Carbon Emissions from Livestock Husbandry

Figure 1 shows the changes and composition of total carbon emissions and carbon intensity of China's livestock husbandry over the years 2008 to 2019. During the study period, the total carbon emissions of China's livestock husbandry showed an inverted U-shaped change. It had little fluctuation, slow growth, and rapid decline. Overall, carbon intensity from livestock husbandry showed an M-shaped fluctuation with two significant and sharp declines. The fluctuations are all characterized by short cycles and violent changes. The second fluctuation dragged the overall values down to a lower point. Between fluctuations, there is persistent downward trend over several years, featuring a large and gentle decline within a long period.

Current and expected changes in China's carbon emissions from livestock husbandry are more affected by CH_4. Currently, the composition and trend of carbon emissions mainly depend on CH_4, the proportion of which in total carbon emissions has increased from 79.74% to 80.93%. This shows the significant influence of CH_4. The enteric fermentation of grass-fed livestock produces 77% of CH_4. The first reason lies in the special rumen structure of grass-fed livestock. The second cause is the small proportion of grass in the forage of grass-fed livestock. Grass-fed livestock in China (especially large-scale) mainly consumes grains, but during the digestion of grains, a higher amount of CH_4 will be emitted. Therefore, if China can develop technologies and equipment to suppress CH_4 emissions of grass-fed livestock in the future and use "grass instead of grain" to feed the livestock, better forage structure can be achieved, and this will help increase livestock amount. In this way, China can still meet social needs by increasing production and maintain or even reduce the carbon intensity with controlled total carbon emissions.

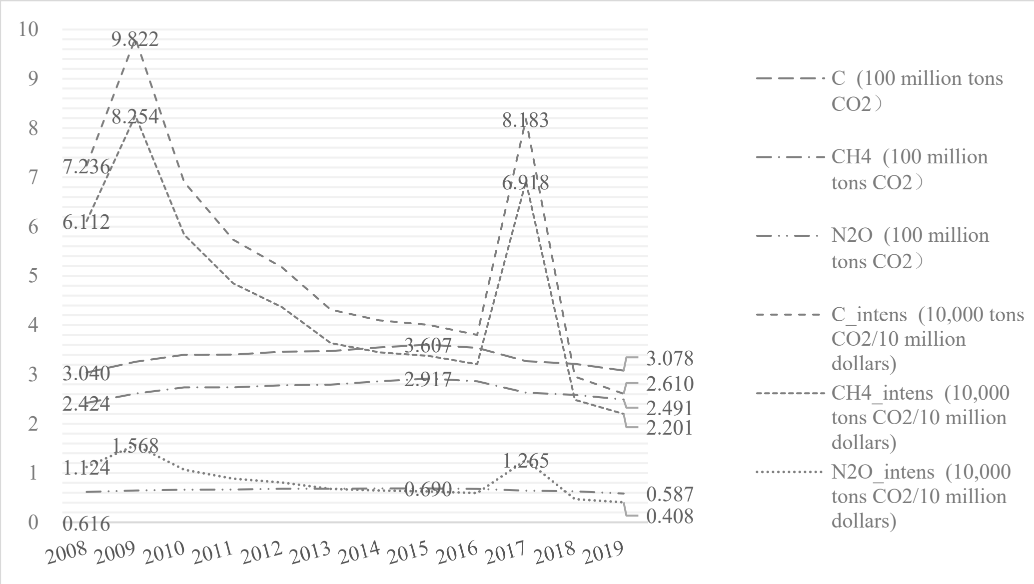

Figure 1. Changes and composition of total carbon emissions and carbon intensity of China's livestock husbandry over the years 2008 to 2019.

3.2.2. Industry Contribution of Carbon Emissions from Livestock Husbandry

Figure 2 shows the average proportion of total carbon emissions and carbon intensity of each livestock industry in China from 2008 to 2019. Grass-fed livestock is the major contributor to carbon emissions of China's livestock husbandry. Moreover, 95% of the carbon intensity comes from grass-fed livestock. The beef industry takes up the highest proportion of total carbon emissions in livestock husbandry and ranks the second in terms of carbon intensity. The pig industry accounts for the second largest proportion in total carbon emissions, but it is also the second-to-last contributor to carbon intensity. Other grass-fed livestock industries have the lowest proportion of total carbon emissions, but their carbon intensity is the highest.

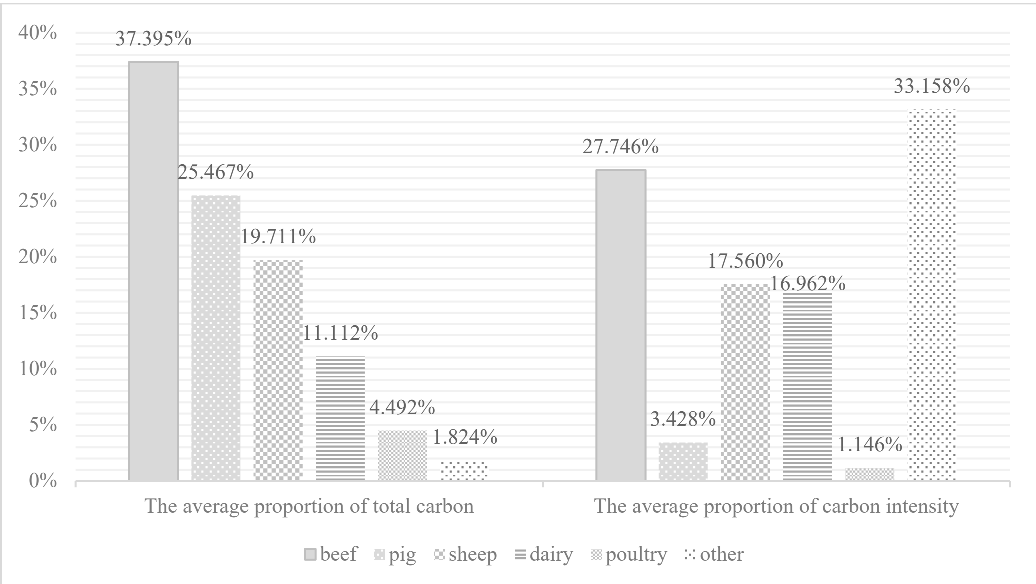

Figure 2. The average proportion of total carbon emissions and carbon intensity of each livestock industry in China from 2008 to 2019.

Scale is another important factor that affects the carbon emissions of livestock industries. First, large-scale livestock industry is characterized by high total carbon emissions but low carbon intensity, and vice versa for small-scale livestock industry. For example, the emission coefficient of pigs is lower than that of sheep, dairy cows and other grass-fed livestock, but large-scale production results in more pigs as well as higher output values than the latter three, so the total carbon emissions of the pig industry is higher, and the carbon intensity is lower. On the contrary, the emission coefficient of other grass-fed livestock industries is much higher than that of pigs, sheep, and poultry, but small-scale production lowers their production and output values, so other grass-fed livestock industries have the lowest total carbon emissions but the highest carbon intensity. However, the degree of scale also affects the results. For grass-fed livestock, beef cattle or sheep's total carbon emissions rankings are lower than their carbon intensity rankings, but dairy cow's ranking follows an opposite pattern. One possible reason is that large-scale production of dairy cows increases the growth rate of total carbon emissions (livestock amount) and makes it exceed the growth rate of the output value (production).

3.2.3. Spatial Distribution of Carbon Emissions of Livestock Husbandry

Table 1 shows the average proportion of total carbon or carbon intensity of livestock husbandry in China from 2008 to 2019. Regardless of total carbon emissions and carbon intensity, the distribution of carbon emissions in China's livestock husbandry can be divided into high, medium, and low emission areas (The total carbon of each province accounts for 0.17–8.76%. The proportion range (0–9) is divided into three equal parts, ranking 1–5, 6–15 and 16–30 as high, medium and low emission areas respectively. The average percentage of provinces in each district is 7.61%, 4.07% and 1.41% respectively. The carbon intensity of each province accounts for 0.98–11.08%, and the proportion range (0–12) is divided into three equal parts. Ranking 1–4, 5–6 and 7–30 are respectively high, medium and low intensity areas, with the average proportion of provinces in each area being 10.25%, 5% and 2.04% respectively), with most of these being low-emission areas. In other words, low-emission areas or low-intensity areas cover most provinces in China. The distribution of the total carbon emissions of livestock husbandry is hilly and scattered, with small differences among areas. The emissions are high in the west and low in the east. The distribution of carbon intensity is concentrated and contiguous, and the average proportion of each area varies greatly. The carbon intensity in livestock husbandry drops significantly, like a "cliff", from west to east, following stepwise declines.

From a spatial point of view, there is a correlation between a province's total carbon emissions and carbon intensity and whether the province is in a grain area. First, most provinces located in the grain areas belong to the high- and medium- emission areas, and these provinces tend to be areas with low carbon intensity. Conversely, provinces that are not in the grain areas but belong to medium-emission areas are all elevated to areas with high carbon intensity. Second, provinces with lower rankings of total carbon emissions and carbon intensity are basically located in grain areas, and the opposite is true when the rankings are increased. The provincial rankings and changes of total carbon emissions and carbon intensity depend on whether the province is in a grain area. The reason is that neighboring provinces share similarities in location, climate, population, transportation, technology, and production methods, resulting in similar livestock structures. However, the cultivated land of every province is different. Since cultivated land is the decisive factor for grain production, and grain is the basic element determining livestock amount, the more cultivated lands are, the higher the livestock amount will be, which will eventually lead to high total carbon emissions from livestock husbandry. Cultivated land is one of the fundamental influencing factors of population, economy, and social development. Population, economy, and society have a huge impact on the supply and demand of livestock products. Therefore, a large amount of cultivated land leads to a high output value of livestock husbandry, which ultimately leads to a low carbon intensity from livestock husbandry.

Table 1. Average proportion of total carbon or carbon intensity of livestock husbandry in China from 2008 to 2019.

Province	Total Carbon Emissions			Carbon Intensity			Major Grain Producing Areas	Economic Region
	Proportion in China	Ranking	Emission Area	Proportion in China	Ranking	Intensity Area		
Henan	8.760%	1	High	1.618%	23	Low	Yes	Central
Neimenggu	8.508%	2	High	9.745%	3	High	Yes	West
Sichuan	7.628%	3	High	2.865%	12	Low	Yes	West
Shandong	6.676%	4	High	1.972%	17	Low	Yes	East
Yunnan	6.479%	5	High	3.790%	7	Low	No	West
Xinjiang	5.298%	6	Medium	11.084%	1	High	No	West
Hunan	5.047%	7	Medium	4.014%	6	Medium	Yes	Central
Hebei	4.825%	8	Medium	1.282%	28	Low	Yes	East
Heilongjiang	4.542%	9	Medium	1.391%	25	Low	Yes	Northeast
Gansu	4.076%	10	Medium	9.212%	4	High	No	West
Qinghai	3.821%	11	Medium	10.973%	2	High	No	West
Liaoning	3.479%	12	Medium	1.796%	20	Low	Yes	Northeast
Hubei	3.316%	13	Medium	1.843%	19	Low	Yes	Central
Jilin	3.255%	14	Medium	2.022%	16	Low	Yes	Northeast
Guizhou	3.085%	15	Medium	5.992%	5	Medium	No	West
Guangxi	2.950%	16	Low	2.490%	13	Low	No	West
Jiangxi	2.502%	17	Low	2.901%	10	Low	Yes	Central
Guangdong	2.427%	18	Low	3.187%	8	Low	No	East
Anhui	2.287%	19	Low	1.626%	22	Low	Yes	Central
Jiangsu	1.793%	20	Low	1.313%	26	Low	Yes	East
Shaanxi	1.777%	21	Low	1.402%	24	Low	No	West
Chongqing	1.491%	22	Low	2.442%	14	Low	No	West
Shanxi	1.489%	23	Low	2.335%	15	Low	No	Central
Ningxia	1.096%	24	Low	2.922%	9	Low	No	West
Fujian	1.065%	25	Low	1.302%	27	Low	No	East
Zhejiang	0.843%	26	Low	1.906%	18	Low	No	East
Hainan	0.686%	27	Low	2.885%	11	Low	No	East
Tianjin	0.354%	28	Low	1.685%	21	Low	No	East
Beijing	0.275%	29	Low	0.980%	30	Low	No	East
Shanghai	0.170%	30	Low	1.024%	29	Low	No	East

3.2.4. Summary

Chen et al., Hu et al., Zhang et al. adopted the IPCC Tier 1 coefficients to calculate total carbon emissions of China's livestock husbandry in 1991–2013, 2000–2007, and 1997–2017 [15,16,25]. This paper uses the IPCC Tier 2 coefficients to estimate total carbon emissions of China's livestock husbandry from 2008 to 2019. The measured values in the same period are very close. Moreover, the years of increase or decrease and the trend are particularly consistent. In addition, Meng et al. and Chen et al. refer only to the carbon emissions from livestock husbandry in a single year to analyze the industrial structure and spatial distribution [20,24]. This paper improves their method by referring to the average percentage of carbon emissions from each industry or province to the total emissions in China over the years. The indicators include absolute and relative changes, as well as static and dynamic changes. This paper supports some of the views of previous studies, but there are also some differences and new conclusions.

First, from 2008 to 2019, the total carbon emissions of China's livestock husbandry showed a steadily inverted U-shaped pattern. The livestock amount will still increase in the future, but the supply-side reform will improve production efficiency. Therefore, the industry's total carbon emissions will likely fluctuate smoothly and decrease. This paper has measured the carbon intensity from livestock husbandry and found a sharp M-shaped decrease. This indicates that the carbon emission efficiency of livestock husbandry in China has improved significantly. In the future, livestock husbandry will enter a stage of high-quality development, and the carbon intensity will be further reduced. However, in terms of dynamic changes, since the relationship between the carbon intensity and total carbon emissions of livestock husbandry is not obvious, it cannot be confirmed that carbon intensity is the primary reason for the decline of total carbon emissions in livestock husbandry [24–26].

Secondly, in livestock husbandry, CH_4 is the main carbon contributor and industrial emissions mainly come from grass-fed livestock. From the perspective of a single industry, cattle and pigs contribute most to overall carbon emissions, and the spatial distribution of this is similar to “hills”. These results are basically the same as existing conclusions [15,20]. The new discovery in this paper is that, in livestock husbandry, the source and industrial contribution of carbon intensity are similar to those of total carbon emissions. However, from the perspective of a single industry, other grass-fed livestock account for the highest proportion while pigs and poultry take up the lowest proportion. The spatial distribution of carbon intensity in livestock husbandry is like a “cliff”.

Finally, the composition, industrial and spatial performances of total carbon emissions and carbon intensity in livestock husbandry are related to CH_4, grass livestock, and grain areas. Such correlations are affected to different degrees by carbon reduction technology, feed structure, breeding scale, and grain output. COVID-19 serves as an unexpected factor that leads to a short-term rapid decrease in total carbon emissions and a sharp increase in carbon intensity of livestock husbandry. This is because the pandemic has resulted in delayed transportation, labor shortages, missed farming seasons, and layoffs of technicians. With insufficient forage supply, unmaintainable scale, tight grain expectations, and less R&D, it has become more difficult to breed and replenish livestock. Furthermore, COVID-19 caused a mismatch of supply and demand, exacerbating the abovementioned shortages in technology, forage, scale, and grains.

4. Analysis of the Influencing Factors of Carbon Emissions of Livestock Husbandry

4.1. Panel Regression Models and Indicators

Referring to the current relevant research [28–31], the following linear model is set in this paper:

$$C_{p,t} = \alpha + \beta X_{p,t} + \varepsilon + \mu \quad (2)$$

The explained variable $C_{p,t}$ is the total carbon emissions of livestock husbandry in each province each year; α denotes the constant term; β represents the regression coefficient; $X_{p,t}$ is the set of explanatory variables of each province each year; ε indicates individual effect term, and μ is the residual term. By replacing the explained variable with $C_{intens,t}$, this paper examines the impact of supply-side factors on the carbon intensity of livestock husbandry. The units of the above carbon emissions and carbon intensity are 10,000 tons and 10,000 tons/10,000,000 US dollars respectively.

(1) With cultivated land area (culti_land) and grassland area (grassland) as explanatory variables, this paper examines the relationship between land structure and carbon emissions from livestock husbandry. As a space carrier and forage source, cultivated land and grassland have a direct impact on output, as crops and grasses will curb the greenhouse effect. Different forage ratios may cause livestock to generate different amount and types of greenhouse gases.

(2) This paper takes dairy cow inventory (dairy), beef cattle inventory (beef), sheep inventory (sheep), pig inventory (pig), poultry inventory (poultry), and other livestock inventory (other) as explanatory variables to examine the relationship between breeding structure and carbon emissions. Livestock inventory determines the output and the amount and intensity of greenhouse gas, but its impacts vary by breed.

(3) Human capital is measured by the number of employees in state-owned enterprises (SOE) in the industry (stat_owned). Because SOE’s employees are more educated and skilled, and they have both environmental awareness and capability, they are more likely to increase the output and reduce carbon emissions.

(4) Livestock husbandry mechanization is represented by the mechanical power (mech_power). High level means more livestock, which indicates greater emissions. However, high

level of mechanization will also increase output and output value and reduce carbon intensity.

(5) Numbers of senior technicians (senior), intermediate technicians (intermediate) and junior technicians (primary) in the industry represent different technology levels. Technology level has a direct impact on the carbon emissions of livestock husbandry. Under different technology levels, the livestock amount, output and output value will have a more complicated relationship between technical level and carbon intensity.

(6) Scale is measured by amounts of large-scale households (large), medium-scale households (medium), small-scale households (small) and below-scale households (below). The impact of scale on carbon emissions in the industry is similar to that of technology.

The units of above-land area, livestock inventory, employees, mechanical power, technicians and households are 10,000 hectares, 10,000 thousand heads, persons, 10,000 kilowatt hours, persons, and households, respectively. In addition, the technical structure is represented by the number of technicians at workstations of all levels, and the scale structure is measured by the number of households of each breed at all scales. After controlling other variables, this paper examines the effects of the factors above on carbon emissions. Relevant data of 21 provinces from 2008 to 2019 come from the 2009–2020 "China Livestock Husbandry and Veterinary Yearbook", "China Environmental Statistical Yearbook", "China Population and Employment Statistical Yearbook", and "China Agricultural Yearbook".

4.2. Empirical Result Analysis

4.2.1. Analysis of Basic Regression Results

In order to explain the reasons for determining the two-way fixed effects model (FE-TW) in detail, we checked it with reference to, and in combination with, the ideas of Chen Qiang, Fei Wei etc., He Weida etc. [35–37], and conducted the following tests with total carbon emissions and carbon intensity as explanatory variables. First, regarding the choice of the fixed effect model (FE) and pooled regression, we conducted a joint hypothesis test (F-test) and a least squares dummy variable (LSDV) test. F-test results show that: $p = 0.0000$, the original hypothesis "H_0: *all* $u_i = 0$" is strongly rejected, and each individual should be allowed to have its own intercept term, that is, the FE is superior to the pooled regression. Since the common standard error is only about half of the cluster robust standard error, and the above F-test does not use the cluster robust standard error, it is not effective. For this reason, LSDV test was carried out, and the results show that dummy variables were significant in some regions. The original assumption that "all individual dummy variables were 0" was rejected, that is, pooled regression should not be used. By adding year dummy variables on the basis of the FE, it is found that for some years dummy variables are significant while for some years they are not. Therefore, the joint significance of all year dummy variables is tested. The results show that: $p = 0.0145$, the original hypothesis of "no time effect" is rejected at the 5% level. Secondly, regarding the choice of the random effects model (RE) and pooled regression. We perform a Lagrange multiplier test (LM test) and maximum likelihood estimation (MLE) of RE. LM test results show that $p = 0.0000$, indicating a strong rejection of the original hypothesis that "there is no individual random effect", that is, that the RE is superior to the pooled regression. As a contrast, MLE was conducted for RE, and the original hypothesis "H_0: $\sigma_u = 0$ ", that is, pooled regression should not be performed. Finally, regarding the choice of FE and RE, we conducted Hausman test and over-identification test. The Hausman test results show that $p = 0.0000$, indicating that the original hypothesis "H_0: u_i is not related to x_{it}, z_i" is strongly rejected, that is, the FE should be used instead of the RE. However, the traditional Hausman test assumes that if H_0 is established, the RE is the most efficient, which requires that u_i and ε_{it} must be independent and distributed. If there is a large difference between the clustering standard error and the common standard error (in this case, the difference is twice), the traditional Hausman test is not applicable. Since the RE has more constraints than the FE that "individual heterogeneity u_i is not related to explanatory variables", it can also be regarded as an over-identification condition, so the over identification test can be carried out. The results show that $p = 0.0000$, indicating that the RE is strongly rejected, so the FE should be used. To sum up, the two-way fixed effects Model (FE-TW) that controls the regional and temporal effects is the most appropriate choice for this paper. Table 2 shows how the various factors affect the total carbon emissions and carbon intensity:

Table 2. Basic regression results.

	I	II
	C	**C_intens**
culti_land	0.0234	−1.150 ***
	(0.0972)	(0.361)
grassland	−0.000818	−0.0170
	(0.00500)	(0.0241)
dairy	0.0311	0.178 **
	(0.0234)	(0.0803)
beef	0.245 ***	0.221 **
	(0.0548)	(0.0853)
sheep	0.248 ***	0.269
	(0.0752)	(0.299)
pig	−0.0195	0.0472
	(0.0682)	(0.491)
poultry	0.0412	0.0215
	(0.0779)	(0.400)
other	0.0189	0.233
	(0.0133)	(0.139)
stat_owned	−0.00222	−0.00643
	(0.00765)	(0.0269)
mech_power	0.0394	0.0361
	(0.0277)	(0.105)
senior	0.0539 *	−0.0677
	(0.0288)	(0.112)
intermediate	−0.104 *	0.398 **
	(0.0583)	(0.187)
primary	0.0539	0.150
	(0.0602)	(0.182)
large	−0.00366	−0.0456
	(0.0241)	(0.0753)
medium	0.0730 **	−0.100
	(0.0261)	(0.0990)
small	0.00480	−0.195
	(0.0539)	(0.129)
below	−0.0293	−0.542 **
	(0.0495)	(0.247)
year	Controlled	Controlled
_cons	3.468 ***	10.95 ***
	(1.098)	(3.117)
N	233	233
R^2	0.849	0.614

Note: *, **, *** respectively mean significant at 1%, 5%, and 10% levels.

(1) The area of cultivated land is positively correlated with the total carbon emissions of livestock husbandry but has a strong negative correlation with the livestock husbandry's carbon intensity. This result supports the view that the total carbon emissions or carbon intensity of livestock husbandry are affected by the grain area distribution. Li et al. [23] consider that using grass instead of concentrate can effectively reduce the carbon footprint. However, the test in this paper shows that grassland area has a slight negative correlation with total carbon emissions and carbon intensity. This is likely because of the constant low proportion of grass supplies from the forage.

(2) The inventory of dairy cows, beef cattle or sheep has a strong positive correlation with the total carbon emissions and carbon intensity of livestock husbandry, while the inventory of pigs has a weak negative correlation with the total carbon emissions of livestock husbandry. This is mainly because the emission coefficients of cattle or sheep are high due to the large inventories associated with them, and that the CH_4 of enteric emissions is often ignored or difficult to collect and process. In comparison, the emission coefficient of pigs is low as most of the emissions come from manure. China now has mature and advanced manure treatment technology and equipment, which has been widely applied in the pig industry. Meanwhile, the larger husbandry scale of hog farming makes the inventory increase even as total carbon emissions decrease. In addition, the results of this paper are related to the views of Zhan et al. [30] who believe that the number of pigs and sheep is positively correlated with methane emissions, while the number of cattle and camels is negatively correlated with methane emissions.

(3) The number of staff employed by state-owned organizations in livestock husbandry has a weak negative correlation with its total carbon emissions and carbon intensity. This group has a deeper understanding and awareness of emission reduction policies, and they master more diversified technologies and active behaviors in terms of pollution removal or emission reduction. However, the small population of this group makes it difficult to realize their full potential.

(4) The mechanical power of livestock husbandry has a positive relationship with its total carbon emissions and carbon intensity. The allocation of dung collection, storage, separation and other machinery for anaerobic digestion and solid–liquid separation can also effectively reduce carbon emissions [38]. At the same time, with the increase of temperature and ventilation, methane emissions will also increase, while temperature control and ventilation equipment in livestock houses play an active role in reducing methane emissions from livestock [39]. However, such special machinery for livestock husbandry is mainly used to increase productivity, such as grass and silage harvesters, forage processing and feeding machines, product collection and primary processing machines, loading and unloading machines and transporters. While these machines reduce the carbon amount per unit of livestock, they increase the total amount of livestock, ultimately leading to an increase in the total carbon emissions of livestock husbandry. However, machinery mainly used for pollution removal or emission reduction has received little attention, especially machinery related to manure removal, manure treatment, and environmental control in livestock houses.

(5) The number of senior technicians in livestock husbandry has a significantly weak positive correlation with its total carbon emissions, but a weak negative correlation with its carbon intensity. This might be caused by the fact that senior technicians have a deeper understanding of policies as leaders in the production process, and so have the awareness and ability to enhance the technology of this sector in line with policy goals to increase output and reduce emissions. However, senior technicians account for a small proportion, and thus have a limited impact on carbon emission reduction. The number of intermediate technicians in livestock husbandry has a significant positive correlation with its total carbon emissions or its carbon intensity, while the number of junior technicians is positively correlated with its total carbon emissions and carbon intensity. It is possible that the abovementioned junior and intermediate technicians focus their techniques on output growth.

(6) The amount of households engaging in large-scale livestock husbandry has a negative relationship with its total carbon emissions and carbon intensity. The amount of households engaging in medium-scale livestock husbandry is significantly positively correlated with its total carbon emissions but negatively correlated with its carbon intensity. As for households engaging in small-scale livestock husbandry, the household amount is positively related to its total carbon emissions and negatively related to its carbon intensity. In comparison, the amount of households engaging in below-scale

livestock husbandry is negatively correlated with its total carbon emissions, and significantly and strongly negatively correlated with its carbon intensity. For large-scale livestock husbandry production, one of the ways to curb carbon emissions is to seek higher output efficiency and lower emissions per livestock. Moreover, the test shows that medium-scale or small-scale livestock husbandry is positively correlated with its total carbon emissions, while below-scale livestock husbandry is negatively correlated with its total carbon emissions and carbon intensity but has the highest emission per livestock, which might be caused by differences in decontamination technology or equipment at different scales. Since large-scale livestock farming is subject to the strongest policy constraints, it generally has chain-type, high-end machines equipping the livestock house for manure removal, manure treatment, environmental control and other technologies and equipment. Husbandry infrastructure nowadays is even equipped with grassland construction, epidemic prevention and other machinery, leading to a greater ability of large-scale decontamination than the growth and accumulation effects of its manure. On the other hand, due to the loose supervision that medium- or small-scale livestock husbandry operations receive, they often have fragmented and low-end decontamination technology or equipment. As a result, their decontamination ability cannot keep up with the growth and accumulation effects of manure. Despite the fact that below-scale farmers have the worst equipment but the highest discharge per livestock, their small amount of livestock inventory cause almost no growth and little accumulation effect of manure.

4.2.2. Examination of the Influence of Technical and Scale Structure

After controlling variants of cultivated land area, grassland area, the inventory of livestock, employee numbers in state-owned units of livestock husbandry and the power of livestock husbandry machinery, this paper further examines the effects of the number of technicians at each workstation for all levels and the effects of households' amounts of each breed of all scales on the total carbon emissions and carbon intensity of livestock husbandry. Table 3 shows how the number of senior technicians at each workstation and the households' amounts of each large-scale breed impact the total carbon emissions and carbon intensity:

(1) Regarding the number of technicians at all levels of grassland stations, the presence of intermediate or primary technicians at veterinary stations is negatively correlated with total carbon emissions. The number of technicians at all levels of improvement stations, senior technicians of veterinary stations and primary technicians of grassland stations is negatively correlated with its carbon intensity. In general, the number of technicians of grassland stations, veterinary stations, and improvement stations of livestock husbandry has a negative relationship with its carbon emissions. The different types of technology mastered by technicians at each workstation are reasons for the differential impact. In terms of specific technologies, methanogenic immunization can reduce the number or activity of methanogenic bacteria in the rumen, thus directly reducing methane emissions [40]. Livestock and poultry breed improvement technology can control carbon intensity from the breeding source, and by improving genetic traits, excellent varieties with higher feed conversion rate and less gas emissions can be obtained [41].

(2) For medium- or small-scale beef cattle, layers of all scales, and small- or below-scale broiler chicken breeding, the number in a household is negatively correlated with its total carbon emissions. In medium-scale dairy cows, large-, medium- or small-scale beef cattle, small-scale sheep, swine farming of all scales, small- or below-scale layers, and large-, medium- or small-scale broiler breeding, the number in households is negatively related to its carbon intensity. In general, large-scale non-grass-fed livestock such as swine, layer, and broiler, and beef cattle under medium-scale, dairy cows, sheep and other grass-fed livestock are more likely to reduce carbon emissions generated by livestock husbandry. As mentioned above, if the decontamination

capacity of a certain scale is greater than the effect of the growth and accumulation of manure, there may be an extensive but low emission effect. However, such a situation relies on the premise that manure is the main pollutant, indicating that large-scale non-grass-fed livestock husbandry is more likely to reduce carbon emissions. For grass-fed livestock—the main CH_4 emitter—large-scale breeding with an increasing amount of livestock will increase and concentrate CH_4, because the current technical equipment for gas emission reduction is neither mature nor widely used. To make things worse, the environment-controlled systems commonly deployed in large-scale operations reinforce this effect. As the CH_4 increase and concentration effects of households below the medium-scale are weaker than those of large-scale breeding, the popularity of environment-controlled systems with them is also lower, so the CH_4 emissions of the grass-fed livestock that are below the medium-scale are covered by the environmental carrying capacity.

Table 3. The regression result of the influence of technical structure and scale structure.

	I	II
	C	**C_intens**
hus_sen	0.0301	0.271
	−0.0349	−0.288
imp_sen	0.0153	−0.0968
	−0.0247	−0.101
gra_sen	−0.00752	0.00156
	−0.00441	−0.0312
fed_sen	−0.00401	−0.0947
	−0.0102	−0.0743
vet_sen	0.0107	−0.101 **
	−0.0121	−0.0434
dairy_lar	0.00728	0.0169
	−0.0185	−0.135
beef_lar	0.012	−0.157 *
	−0.0125	−0.0894
sheep_lar	0.00677	0.0629
	−0.00816	−0.0749
pig_lar	−0.0334	−0.27
	−0.036	−0.184
layer_lar	−0.00486	0.115
	−0.0113	−0.0793
broiler_lar	−0.00416	−0.235
	−0.0103	−0.142
culti_land	Controlled	Controlled
grassland	Controlled	Controlled
dairy	Controlled	Controlled
beef	Controlled	Controlled
sheep	Controlled	Controlled
pig	Controlled	Controlled
poultry	Controlled	Controlled
other	Controlled	Controlled
stat_owned	Controlled	Controlled
mech_power	Controlled	Controlled
year	Controlled	Controlled
_cons	2.089 ***	13.47 **
	−0.566	−5.467
N	134	134
R^2	0.949	0.566

Note: *, **, *** respectively mean significant at 1%, 5%, and 10% levels.

4.2.3. Summary

First, livestock husbandry carbon emissions are obviously affected by factors including land structure, breeding structure, technical level, and scale level. For the land structure, expanding cultivated land significantly reduces the carbon intensity in livestock husbandry, while a larger grassland does not significantly contain the carbon emissions in livestock husbandry, indicating the necessity to develop the grass industry and optimize the allocation of grain and grass resources. For the breeding structure, the livestock husbandry carbon emissions grow significantly with an increasing inventory of grass-fed livestock, while the increase in pig inventory fail to substantially reduce the livestock husbandry carbon emissions. In light of this, we can see that not all increases in livestock inventory will lead to more livestock husbandry carbon emissions. Instead, this is determined by the degree of compatibility between the carbon emission source and the equipment used for the processing techniques. At the technical level, more senior technicians insignificantly reduce livestock husbandry carbon intensity, however, the presence of more intermediate technicians drastically increases total carbon emissions of livestock husbandry. Accordingly, despite the fact that a higher technical level can effectively reduce the carbon emissions of livestock husbandry, livestock husbandry techniques in China are still at the intermediate or primary level. For scale level, more large-scale households do not significantly inhibit the total carbon emissions or carbon intensity of livestock husbandry. In comparison, more below-scale households can reduce the total carbon emissions generated by livestock husbandry and dramatically further decrease the carbon intensity, while the growth of medium-scale households will lead to much higher total carbon emissions. Given this, under the dual goals of output and carbon reduction, large-scale or featured livestock breeding should be supported. In addition, analysis shows that the technique level and popularization of pollution removal technology and equipment will play a decisive role in carbon emission reduction for livestock husbandry at different scales.

Second, livestock husbandry carbon emissions are slightly affected by the level of human capital or mechanization. Growth in the employment of state-owned organizations in the livestock husbandry industry only reduce the total carbon emissions or carbon intensity to a minimal degree. It is expected that an improved level of human capital will curb the carbon emissions of livestock husbandry. However, only a minority of technicians and employees in the industry could contribute to the carbon emission reduction, most livestock husbandry practitioners may reach a similar level through publicity, training or demonstration. Meanwhile, higher mechanical power fails to significantly increase the total carbon emissions or carbon intensity of livestock husbandry, mainly because machinery in current livestock husbandry is still output-oriented. Future development should pay more attention to pollution-removing or emission-reducing machinery.

Finally, the technological and scale structure also significantly affect the carbon emissions of livestock husbandry. The number of technicians serving at grassland stations, veterinary stations and improvement stations has a negative relationship with the total carbon emissions and/or carbon intensity of livestock husbandry, indicating that technologies related to pasture cultivation, diseases control or species improvement may help reduce the carbon emissions in livestock husbandry. Large-scale breeding of non-grass-fed livestock such as pigs, layers, and broilers, and under medium-scale breeding of beef cattle, dairy cows, sheep and other grass-fed livestock are more likely to contain livestock husbandry carbon emissions. Therefore, it is reasonable to promote the continuing growth of those large-scale species. Furthermore, analysis shows that technologies and equipment used exclusively for carbon emissions reduction may be a key factor for a larger scale of grass-fed livestock.

In the short term, due to the epidemic, the total amount of livestock, the proportion of grass-fed livestock or the scale of livestock rapidly decrease the carbon emissions in livestock husbandry but substantially increase the carbon intensity. During the COVID-19 pandemic, the transportation and logistics blocks led to forage shortage, growing price and cost of forage. Livestock slaughtering delay has been an industry-wide problem due to low resumption rates in slaughtering businesses and difficulties in livestock sales. Due to the above factors, firms and farmers are unwilling to restock, resulting in a further reduction in the total livestock amount. The shortage of forage is mainly caused by the lack of green roughage such as grass or silage. This is especially so in areas suffering insufficient grass resources, where "green wheat is cut for silage". In terms of demand, grass-fed livestock product sales are the biggest victims of the pandemic, forcing the industry to "pour milk and kill cows", though occasionally. The double shock to supply and demand also cut the proportion of grass-fed livestock in the breeding structure. Small-scale breeding, to some extent, is self-sufficient. Issues such as the shortage of forage, sales difficulty or restock reduction caused by COVID-19 have become severe as the scale of breeding has grown larger. On top of these, and coupled with slower capital turnover, medium- or large-scale farmers have been forced to downsize or exit the industry directly. In the long post-COVID era, as the amount of livestock and the proportion of grass-fed livestock has increased with a better structured industry model, the carbon intensity will drop significantly despite a slowing down of the total carbon emissions reduction. COVID-19 has an indirect impact on the production of livestock husbandry as mentioned above, but this impact is also short-term and localized due to the long growth cycle of livestock, especially grass-fed livestock such as cattle or sheep. During the epidemic, measures such as "green channel", "production and marketing connection", and "business resumption supports", implemented by the state and local governments, have mitigated the negative impacts of the pandemic, promoting production recovery. In the post-epidemic period, the production, consumption or trade of livestock husbandry will gradually recover, and the supply and demand of livestock products, especially grass-fed livestock products, will rebound. In addition, the optimized planting, breeding and scale structure of livestock husbandry, as well as the promotion of "grass-for-grain" and the integration of the three industries (agriculture production, agricultural product processing and agricultural product sales services) will lead to a slowing of the decrease in total carbon emissions but a greatly dropping carbon intensity.

5. Conclusions and Recommendations

This paper takes the carbon emissions in China's livestock husbandry as the research object. According to our measurement, (1) total carbon emissions showed an inverted U-shaped change and carbon intensity decline showing an M-shaped curve during the study period, (2) total carbon emissions and carbon intensity are mainly composed of CH_4 that is generated mainly by grass-fed livestock industries with spatial distribution patterns of "hill" and "cliff", respectively, while the spatial expression of these two factors is related to the distribution of grain areas. As the test on supply side factors shows, (1) the carbon emissions of livestock husbandry are apparently affected by its land structure, breeding structure, technical level and scale level; however, (2) the impact of the level of human capital and mechanization is not as significant as that of technological structure and scale structure.

As far as policy makers are concerned, they should make it clear that whether the goal of restricting the carbon emissions of livestock husbandry is to reduce the total amount or intensity, and different regions or different industries should choose different targets according to their own conditions, they should require that the proportion of grass-fed livestock be appropriately reduced in "livestock without grass" areas, and the proportion of grass-fed livestock should be appropriately increased in "grass without livestock" areas. They should expand the senior titles of technicians within the scope of the policy, focusing on the development of technologies and equipment related to forage planting, epidemic prevention and control, animal breed improvement, decontamination and emission reduction.

As far as the livestock husbandry department is concerned, in the post-epidemic period, the department needs to keep sufficient reserves of commonly used veterinary drugs, forage, disinfectant, protective clothing and other materials to deal with major sudden outbreaks. The department should strive for subsidy policies related to harmless land use and improved seed subsidies that are conducive to increasing production and reducing emissions. The department should promote the integrated development of forage planting, feed production, livestock and poultry breeding, slaughtering and processing, cold chain logistics, storage and sales.

As far as farmers are concerned, as carbon emission constraints will become more and more stringent, so large-scale aquaculture will have greater risks, but agglomeration in the region mean that medium- or small-scale aquaculture-based has become a feasible path. Farmers in grain areas still have advantages in raising non-grass livestock such as pigs and chickens. Farmers in pastoral areas should plant forage as much as possible while raising cattle, sheep and other grass-fed livestock, which is conducive to dealing with the increasingly stringent carbon emission policies of livestock husbandry.

6. Deficiency and Prospect

Because the carbon emissions of livestock husbandry come directly from livestock, this paper assumes that the factors that directly affect the number of livestock, such as land structure, animal structure, human capital level, mechanization level, technology level, scale level, etc., will affect the carbon emissions of livestock husbandry. However, paying attention to the impact of supply-side factors on carbon emissions of livestock husbandry is not only the perspective of this paper, but also the limitation of this paper.

There are many factors that affect the carbon emissions of livestock husbandry, such as land price outside the production process, consumption of livestock products, highway density, Engel coefficient, urbanization rate and so on [28]. Moreover, greenhouse gas emissions show varying degrees of persistence or long-term memory, while permanent/transitory policies have different effects on greenhouse gas emissions, so livestock husbandry policies will have a more comprehensive and systematic impact on their carbon emissions [42]. However, due to the limitation of space and data availability, these factors are not discussed in this paper.

As far as future research is concerned, on the one hand, we can consider adding more feasible factors to explore the problem more comprehensively, and special attention should be paid to the long memory of carbon emissions of livestock husbandry and the impact of policies on it. On the other hand, the relationship between carbon emissions and production efficiency of livestock husbandry is also a matter of concern, and special attention should be paid to the factors beneficial to carbon emissions and to the production efficiency of livestock husbandry at the same time.

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Abbreviations

LCA	Life Cycle Assessment
LMDI	Logarithmic Mean Index Method
OLS	Ordinary Least Squares
FE	Fixed Effects Model
IPCC	Intergovernmental Panel on Climate Change
F-test	Joint Hypotheses Test
LSDV	Least Square Dummy Variable
LM	Lagrange Multiplier Method
MLE	Maximum Likelihood Estimation
RE	Random Effects Model
FE-TW	Two-way Fixed Effects Model
SOE	State-owned Enterprises

References

1. Notice of The State Council in China on the Issuance of an Action Plan for Peaking Carbon Emissions before 2030. Available online: http://www.gov.cn/zhengce/content/2021-10/26/content_5644984.htm (accessed on 26 December 2022).
2. World Meteorological Organization: Global Greenhouse Gas Emissions Set a New Record. Available online: https://baijiahao.baidu.com/s?id=1714676703171763961&wfr=spider&for=p (accessed on 26 December 2022).
3. Qu, S.; Chen, W.M.; Liu, L.J.; Hu, Y.C.; Yu, Y.L.; Zhai, B.Y.; Zhou, Q. China's CO_2 emission trends and mitigation strategy in the post COVID-19 era. *Chin. J. Environ. Manag.* **2021**, *13*, 8–18. [CrossRef]
4. Zhao, M.J. Making overall plans and taking into account various challenges. *Econ. Dly.* **2021**, *11*, 3.
5. Tian, C.S.; Chen, Y. China's provincial agricultural carbon emissions measurement and low carbonization level evaluation: Based on the application of derivative indicators and TOPSIS. *J. Nat. Resour.* **2021**, *36*, 395–410. [CrossRef]
6. Luo, B.L. Agricultural development during the high incidence period of epidemics: New challenge. *J. Huazhong Agric. Univ. Soc. Sci. Ed.* **2020**, *3*, 1–6+168. [CrossRef]
7. Meng, G.H.; An, K.; Lu, Q.F. The effect of COVID-19 on agricultural production from the micro point of view—A sample from 130 counties in an eastern agricultural province of China. *J. China Agric. Univ. (Soc. Sci.)* **2020**, *37*, 32–42. [CrossRef]
8. Tang, B.J.; Ji, C.J.; Wang, X.Y.; Chen, J.Y.; Li, D.H. Impact of national carbon market policy on economy and emissions in the post COVID-19 period. *Chin. J. Environ. Manag.* **2021**, *13*, 19–27. [CrossRef]
9. Franz, W.; Adrian, L. Greenhouse gas emissions from the EU livestock sector: A life cycle assessment carried out with the CAPRI model. *Agric. Ecosyst. Environ.* **2012**, *149*, 124–134. [CrossRef]
10. Prado, A.D.; Mas, K.; Prado, G.; Gallejones, P. Modelling the interactions between C and N farm balances and GHG emissions from confinement dairy farms in northern Spain. *Sci. Total Environ.* **2013**, *465*, 156–165. [CrossRef]
11. Vergea, X.; Maximeb, D.; Desjardinsc, R.L.; VanderZaagc, A.C. Allocation factors and issues in agricultural carbon footprint: A casestudy of the Canadian pork industry. *J. Clean. Prod.* **2016**, *113*, 587–595. [CrossRef]
12. Carlos, C.C.; Cindy, S.M.; Priscila, A.A.; Guilherme, S.R.; Carlos, E.P. Assessing the carbon footprint of beef cattle in Brazil: A case study with 22 farmsin the State of Mato Grosso. *J. Clean. Prod.* **2016**, *112*, 2593–2600. [CrossRef]
13. Zervas, G.; Tsiplakou, E. An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. *Atmos. Environ.* **2012**, *49*, 13–23. [CrossRef]
14. Annette, F. Regionalised inventory of biogenic greenhouse gas emissions from European agriculture. *Eur. J. Agron.* **2003**, *19*, 135–160. [CrossRef]
15. Zhang, J.X.; Wang, H.L. Regional difference, dynamic evolutionary and convergence analysis on the chinese animal husbandry—Based on the animal husbandry data in 31 provinces from 1997 to 2007. *Jianghan Trib.* **2020**, *9*, 41–48. [CrossRef]
16. Hu, X.D.; Wang, J.M. Estimation of livestock greenhouse gases discharge in China. *Trans. Chin. Soc. Agric. Eng.* **2010**, *26*, 247–252. [CrossRef]
17. Wei, X.L.; Gao, L.H.; Xu, J.; Zhu, J.S.; Jing, Y.T. Evaluation on greenhouse gas emission of livestock in chongqing city. *Southwest China J. Agric. Sci.* **2013**, *26*, 1235–1239. [CrossRef]
18. Bai, M.; Ma, W.L.; Wu, J.F.; Lu, Y.Q.; Ren, K.; Kang, J.W. Evaluation on greenhouse gas emission of scale dairy farms in Beijing. *J. Domest. Anim. Ecol.* **2017**, *38*, 78–85. [CrossRef]
19. Ban, R.B.; Wang, J.L.; Feng, K.Y.; Wu, T.L. Study on spatial-temporal difference of carbon emission from livestock and poultry breeding in Anshun city. *Areal Res. Dev.* **2017**, *36*, 151–155. [CrossRef]
20. Meng, X.H.; Cheng, G.Q.; Zhang, J.B.; Wang, Y.B.; Zhou, H.C. Analyze on the spatialtemporal characteristics of GHG estimation of livestock's by life cycle assessment in China. *China Environ. Sci.* **2014**, *34*, 2167–2176. [CrossRef]
21. Luo, T.; Yue, Q.; Yan, M.; Cheng, K.; Pan, G.X. Carbon footprint of China's livestock system-a case study of farm survey in Sichuan province, China. *J. Clean. Prod.* **2015**, *102*, 136–143. [CrossRef]
22. Zhuang, M.H.; Gong, B.Z.R.; Li, W.J. Greenhouse gas emission of pastoralism is lower than combined extensive/intensive livestock husbandry: A case study on the Qinghai-Tibet Plateau of China. *J. Clean. Prod.* **2016**, *147*, 514–522. [CrossRef]

23. Li, T.Y.; Xiong, H.; Wang, M.L. How does China's dairy industry develop under "the carbon peaking and carbon neutrality goal": Study on carbon emission of dairy industry from the perspective of whole industry chain. *Issues Agric. Econ.* **2022**, *2*, 17–29. [CrossRef]
24. Chen, Y.; Shang, J. Estimation and effecting factor decomposition of green house gas emission of animal husbandry industry in four pastoral areas. *China Popul. Resour. Environ.* **2014**, *24*, 89–95. [CrossRef]
25. Chen, S.; Hu, H. Study on the spatial-temporal changes and influence factors of greenhouse gases emission from livestock and poultry in China. *China Popul. Resour. Environ.* **2016**, *26*, 93–100. [CrossRef]
26. Yao, C.S.; Qian, S.S.; Mao, Y.H.; Li, Z.T. Decomposition of impacting factors of animal husbandry carbon emissions change and its spatial differences in China. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 10–19. [CrossRef]
27. Zhou, J.; Qing, P.; Yan, T.W. Technology progress, production intensification and greenhouse gas emission reduction in China's pig breeding. *J. Huazhong Agric. Univ. (Soc. Sci. Ed.)* **2018**, *4*, 38–45+167. [CrossRef]
28. Tian, S.Y.; Zheng, W.W.; Zhou, L. Characteristics of environmental Kuznets curve for the low carbon breeding in China and its causes. *Resour. Sci.* **2012**, *34*, 481–493.
29. Yao, C.S.; Qian, S.S.; Li, Z.T.; Liang, L.W. Provincial animal husbandry carbon emissions in China and temporal-spatial evolution mechanism. *Resour. Sci.* **2017**, *39*, 698–712. [CrossRef]
30. Zhan, J.; Zhang, J.N.; Deng, R.R. Path selection of low-carbon development of animal husbandry in China: Regression analysis of methane growth based on animal husbandry emission sources. *Soc. Sci. Guangxi* **2012**, *9*, 50–54. [CrossRef]
31. Min, J.S.; Zhou, L. Do systematization reduced carbon emissions of scale hog raising households? Evidence from the 229 scale hog raising households of three cities in Jiangsu province. *Issues Agric. Econ.* **2014**, *35*, 35–42+110. [CrossRef]
32. Preparation Committee for the Second National Assessment Report on Climate Change. *Second National Assessment Report on Climate Change*; Science Press: Beijing, China, 2011.
33. Dong, H.M.; Lin, E.D.; Li, Y.E.; Rao, M.J.; Yang, Q.C. Preliminary estimation of methane emission from agricultural system in China. *AMBIO-A J. Hunman Environ.* **1996**, *25*, 292–295.
34. Shi, S.; Li, C.X.; Li, M.T. Review of research from carbon emissions to carbon footprint in livestock husbandry. *China Popul. Resour. Environ.* **2017**, *27*, 36–41. [CrossRef]
35. Chen, Q. *Advanced Econometrics and Stata Applications*, 2nd ed.; Higher Education Press: Beijing, China, 2014; pp. 250–271.
36. Fei, W.; Yu, B.X.; Wang, W.G. Digital Economy Development and Carbon Emission Reduction-Theoretical Deduction and Empirical Test. *Economist* **2022**, *11*, 74–83. [CrossRef]
37. He, W.D.; Wen, J.L.; Zhang, M.Y. Can Tax Reduction and Fee Reduction Enable Enterprises to Develop with High-quality? *Econ. Probl.* **2022**, *1*, 1–8+30. [CrossRef]
38. Horacio, A.A.; Rebecca, A.L. Evaluating greenhouse gas emissions from dairy manure management practices using survey data and lifecycle tools. *J. Clean. Prod.* **2016**, *143*, 169–179. [CrossRef]
39. Jernej, P.; Michael, Z.; Sabine, S. Effects of housing system, floor type and temperature on ammonia and methane emissions from dairy farming: A meta-analysis. *Biosyst. Eng.* **2019**, *182*, 16–28. [CrossRef]
40. Buddle, B.M.; Denis, M.; Attwood, G.T.; Altermann, E.; Janssen, P.H.; Ronimus, R.S.; Pinares-Patiño, C.S.; Muetzel, S.; Wedlock, D.N. Strategies to reduce methane emissions from farmed ruminants grazing on pasture. *Vet. J.* **2010**, *188*, 11–17. [CrossRef] [PubMed]
41. Silvestre, T.; Lima, M.A.; Santos, G.B.D.; Pereira, L.G.; Machado, F.S.; Tomich, T.R.; Campos, M.M.; Jonker, A.; Rodrigues, P.H.; Brandao, V.L.; et al. Effects of feeding level and breed composition on intake, digestibility, and methane emissions of dairy heifers. *Animals* **2021**, *11*, 586. [CrossRef]
42. Bikramaditya, G.; Spyros, P.; Vandana, G. Are policy stances consistent with the global GHG emission persistence? *Appl. Energy Financ.* **2022**, 255–279. [CrossRef]