

Article

Evaluation of the Regional Livestock High Quality Development in China Based on Spatial–Temporal Heterogeneity

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Abstract: The livestock high-quality development (LHIQUD) is an important guarantee for promoting livestock modernization and sustainability. The scientific evaluation of LHIQUD and its regulations is significant to solving the key problems in livestock sustainability and promoting LHIQUD. This paper holds that LHIQUD is influenced by the cutting-edge view of economic development and ecological civilization construction, driven by innovation and the change in quality and efficiency. Its fundamental goal is to satisfy people's growing demand for safe, high-quality agricultural products. Finally, it will realize the sharing of development achievements and enhance competitiveness of the livestock. Based on this, the study sets up an evaluation system for LHIQUD, including indicators of quality and efficiency improvement, coordination and sharing, green development, and innovative development. The entropy method, exploratory spatial data analysis, and kernel density estimation method are used to evaluate the regional LHIQUD of China from 2010 to 2019. The dynamic evolution and spatial auto-correlation analysis results show that (a) Regional LHIQUD in China has generally improved, and there is a decreasing trend from the East, Northeast, and central region to the West, with the characteristics of spatial non-equilibrium. (b) LHIQUD is positively correlated with the regional economic development. (c) The spatial auto-correlation of LHIQUD is not obvious, generally showing a weak agglomeration pattern. Provincial LHIQUD is interdependent in geographical space, with agglomeration characteristics. The findings of this study are invaluable for governments at all levels to accurately comprehend the true state of regional LHIQUD in China, thereby providing a solid foundation for formulating corresponding policies.



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Keywords: livestock sustainability; high-quality development; spatial–temporal evaluation; spatial disequilibrium

1. Introduction

The incremental growth in China's livestock production has been a significant contributing factor in ensuring the availability of animal products, stimulating rural economic activity, and enhancing the income of farmers. However, there are also prominent problems such as the low quality and efficiency of industrial development [1,2], the imperfect system of innovative and green development [3], and the low coordination and sharing. Therefore, a scientific assessment of LHIQUD is very critical. It facilitates the resolution of pivotal issues pertaining to livestock evolution and the advancement of LHIQUD.

The existing studies focus on the connotation, evaluation, and path of LHIQUD. As China puts forward the concept of high-quality development, the academic community constantly improves the implications in the economy and manufacturing industries [4,5]

and explains the agricultural high-quality development (AHIQUD) from different perspectives [6,7]. It also explains AHIQUD from the perspective of improving productivity, agricultural product quality, and market competitiveness [8–11]. However, there are few studies on LHIQUD. Chen Liangwei [12] posits that LHIQUD should adhere to the direction of ecological agriculture, thereby establishing a novel developmental paradigm that is characterized by efficient production and industrial integration. Xiong Xuezheng [13] asserts that the objective of LHIQUD is to effectively coordinate the interplay between livestock production, resources, and the environment. This entails optimizing the structure and mode of livestock production, establishing a more robust system for resource support, epidemic prevention and control, processing, and circulation. Ultimately, this comprehensive approach aims to enhance the quality, efficiency, and competitiveness of the industry. A modern pattern of livestock featuring green and circular development, improved supply quality and efficiency, and optimized operation and management will be formed. Wang Mingli and Yu Fawen et al. [14,15] expound the theoretical connotation of LHIQUD from the perspective of the goal, background, and ecological orientation.

Additionally, scholars have developed an evaluation system of LHIQUD from different perspectives. Firstly, it is based on four key aspects: green development, quality and efficiency improvement, scale development, and industrial integration under industrial integration [16]. Secondly, it encompasses the five dimensions of innovation, coordination, greenness, openness, and sharing [17]. Thirdly, from the perspective of the industry chain, the livestock industry can be divided into four dimensions: upper, middle, lower, and resource utilization [18]. Fourthly, the three dimensions of animal husbandry are operation and management optimization, green cycle development, and supply quality and efficiency improvement. Finally, the evaluation system is based on seven dimensions: industrial efficiency, farmers' income, management quality, green development, product quality, international competitiveness, and production efficiency. In addition, some scholars have constructed an evaluation index system for LHIQUD in the feed industry, taking into account both demand and supply. The entropy method, analytic hierarchy process (AHP), and "vertical and horizontal" splitting grade method are the most commonly used methods for evaluating AHIQUD. In addition, the Moran index method and the coupling degree model have also been devoted to study the spatial correlation of AHIQUD and the coupling relationship of subsystems in the industrial chain [19].

Scholars have proposed a number of strategies to promote the LHIQUD from many aspects; these encompass the construction of systems, development models, supply–demand relationships and scientific and technological innovations [20,21]. With the new development concept, it is imperative to establish a mechanism of resources for the optimal utilization of livestock and poultry waste through the improvement of the market mechanism and the strengthening of supervision. It is necessary to formulate development strategies for the livestock industry according to local conditions and establish a modern livestock industry system and macro-control system. In addition, according to resource and environmental constraints [22], governments should rationally distribute the livestock production with financial support [23] and vigorous modern scientific and technological support [24–26].

Although some progress has been made in current research, further exploration is required in the following areas. There are lots of studies in the field of AHIQUD, but few have focused on the problems of LHIQUD, and even fewer have evaluated LHIQUD. First, the concept of LHIQUD is defined on an insufficient theoretical basis, focusing exclusively on the process and results of the livestock industrial chain. Second, the evaluation model of LHIQUD is inadequate in that it does not take into account the deep-seated reasons for the differences in the regional industry. The concept of LHIQUD is defined with

insufficient theoretical basis and lacks empirical evidence. Furthermore, the analysis of the underlying causes of the discrepancies in LHIQUD at the regional level is inadequate, and the implementation of policies is not targeted.

In light of the aforementioned, the marginal contributions of this study can be delineated below. First, combining China's livestock industry's "dual carbon" goals and policy orientation comprehensively explain the connotation of LHIQUD with enhancing livestock production efficiency and low-carbon technology innovation, which will coordinate the relationship between stable production and livestock supply and low-carbon development, and promote green development in the livestock industry. Second, incorporating the "dual carbon" objectives into the evaluation index system for LHIQUD encompasses four dimensions: quality enhancement and efficiency improvement, coordinated sharing, green development, and innovation-driven development. The indicators include wastewater management, biogas utilization, total mechanical power, carbon emissions, and the number of green food certifications within the livestock sector. This approach addresses the limitations of the existing research, which has often overlooked the carbon emissions associated with LHIQUD. Third, in consideration of the spatial heterogeneity of livestock resource endowment, the ratio method is employed to quantify each index, thereby facilitating an objective presentation of the LHIQUD. Fourth, the entropy method, the exploratory spatial data analysis method, and the kernel density estimation method are utilized to explore the spatial-temporal evolution characteristics of China's LHIQUD regionally. Ultimately, the paper examines the underlying causes of the discrepancies in regional LHIQUD and proposes strategies to effectively advance LHIQUD.

The structure of the study is as follows: Section 2 presents the research methodologies and data source. Section 3 outlines the results of LHIQUD. Section 4 contains the conclusions and suggestions of the study.

2. Material and Methods

2.1. Research Methods

2.1.1. Entropy Method

Previous studies have used various methods for empirical evaluation. These include subjective weighting methods such as the AHP and Delphi method, which require researchers to possess extensive experience and knowledge. In addition, objective weighting methods such as principal component analysis, factor analysis, and the entropy method are more reliable because they do not rely on subjective judgments. Among these methods, the first two require a sufficient sample size, and it is difficult to determine the actual significance of the new variables following dimensional reduction through factor analysis. Compared with the subjective weighting methods, the entropy method mainly determines the weights based on the quality of information associated with each indicator, thereby reducing the potential for human bias and yielding relatively objective results [5,6]. Accordingly, this method was selected for the purposes of this study.

- (1) Set up the original data matrix. $A = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$. The x_{ij} is the original data of the j index in the i year.
- (2) Dimensionless processing. It is necessary to standardize the original data due to the attribute difference in the indicators in LHIQUD. The extreme value method, which is widely used, is adopted in this study. Specific steps are shown below.

Positive indicators of LHIQUD:

$$x'_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (1)$$

Negative indicators of LHIQUD:

$$x'_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}} \quad (2)$$

x_{ij} is the original index, x'_{ij} is the standardized data, and $\min x_{ij}$ and $\max x_{ij}$ represent the minimum and maximum values of x_{ij} , respectively.

(3) Set up the normalized matrix

$$P_{ij} = \frac{x'_{ij} + k}{\sum_j^n (x'_{ij} + k)} \quad (3)$$

In order not to have a significant impact on the standardized data, the k should be as small as possible.

(4) Evaluate the entropy value of the j index

$$e_j = -k \sum_{i=1}^m p_{ij} \ln p_{ij} \quad (4)$$

The k is constant, $k = 1/\ln n$.

(5) Evaluate the information entropy redundancy of j index

$$\delta_j = 1 - e_j \quad (5)$$

(6) Evaluate the weight

$$w_j = \delta_j / \sum_{j=1}^n \delta_j \quad (6)$$

(7) Evaluate the overall score

$$S_i = \sum_{j=1}^n w_j x'_{ij} \quad (7)$$

W_j is the weight of indicator j in the evaluation index system of LHIQUD. Subsequently, each criterion layer of the samples should be scored and evaluated using the multi-objective linear weighting function method, as outlined in Equation (6). The entropy method and the multi-objective linear weighting function are used to evaluate the comprehensive index of regional LHIQUD (S_i). A higher S_i value indicates a greater degree of LHIQUD in the region.

2.1.2. Kernel Density Estimation Method

Both non-parametric estimation and parametric estimation have been widely used in contemporary research, with non-parametric estimation offering the advantage of circumventing the necessity to calibrate the sensitivity of the model. Kernel density estimation is a crucial non-parametric method for studying the dynamic evolution trend of a sample distribution, which is well suited for this study [7]. By considering the density function of the random variable, it is possible to estimate the probability density of x at a specific point using Equation (9).

$$f(x) = \frac{1}{Nh} \sum_{i=1}^N K\left(\frac{X_i - x}{h}\right) \quad (8)$$

$$K(x) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \quad (9)$$

where N is the number of location points, bandwidth h represents a smoothing parameter, K is a Gaussian Kernel, X_i represents the LHIQUD in the sample province, and $f(x)$ represents the probability density. The distribution position indicates the degree of LHIQUD. The height and width of the peaks reflect the regional differences in LHIQUD. The number of peaks indicates the phenomenon of polarization. Extensibility is used to reflect the difference between the highest and lowest degrees of LHIQUD within and between provinces. The lengthening of the trailed end of the curve indicates a greater difference.

2.1.3. Exploratory Spatial Data Analysis Method (ESDA)

The ESDA is used to detect whether there is spatial auto-correlation among regions. Global spatial correlation is a description of the spatial characteristics of LHIQUD across the entire region, which is measured by the Moran's I Index [17,19]. The specific formula is shown below.

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{S^2 \sum_{i=1}^n \sum_{j=1}^n w_{ij}} \quad (10)$$

$$S^2 = \frac{1}{n} \sum_{i=1}^n (X_i - \bar{X})^2 \quad (11)$$

where X_i and X_j represent the observed values of LHIQUD of diverse regions. W_{ij} is a space weight matrix defining whether geographic regions i and j are adjacent or not. S^2 is the variance of the observed LHIQUD, and n represents the number of provincial units.

The Global Moran Index describes the auto-correlation of LHIQUD, which weighs the similarity of each province and reflects the spatial auto-correlation features of the whole data set. The Local Moran Index reflects the auto-correlation of each province in its neighborhood, focusing on the local auto-correlation, reflecting the provincial features in space.

$$I_i = \frac{(X_i - \bar{X}) \sum_{j=1}^n w_{ij} (X_j - \bar{X})}{S^2} \quad (12)$$

As with Equation (10), the indicators have the same interpretation. Positive auto-correlation clusters indicate the high-high or low-low aggregation of LHIQUD, while negative correlation clusters indicate the high-low or low-high aggregation of LHIQUD.

2.2. Evaluation System

2.2.1. Connotation of LHIQUD

The Fifth Plenary Session of the 19th Central Committee of the Communist Party of China proposed the concept of innovative, coordinated, green, open, and shared development, which should run through the whole process and all fields. Therefore, we must adhere to the guidance of the frontier development vision and promote LHIQUD. The 2020 document, entitled "Opinions on Promoting LHIQUD", emphasized the necessity of maintaining and enhancing the quality, efficiency, and overall competitiveness of livestock in order to achieve LHIQUD and to improve the green evolution and circular development of livestock and consolidate the achievements of sustainable livestock continuously. Moreover, the application of innovative technological platforms, such as mobile internet and big data in livestock, should also be strengthened. In 2021, the "No. 1 Central Document" indicated that it is necessary to address the issues of imbalance and inadequacy in development by establishing a new development pattern and ensuring the equitable distribution of development benefits [27]. The coordination and sharing of resources are intrinsic to the sustenance

of a healthy economy. In 2024, the “No. 1 Central Document” further emphasized the promotion of increasing the quantity and quality of animal husbandry [28].

In conclusion, combined with the ‘dual-carbon’ goals and policy orientations of China’s livestock industry, this article comprehensively elaborates on the connotation of LHIQUD to the aspects of improving the production efficiency of the livestock industry, promoting the innovation of low-carbon livestock industry technologies, coordinating the sharing of achievements, and advancing the green development of livestock industry. In addition, it should be practical to reduce emissions and maintain quality and quantity in the livestock industry. Therefore, quality and efficiency improvement are a fundamental requirement for achieving the high-quality development of China’s livestock industry. First, the quality and efficiency improvement. The livestock industry of China has achieved a number of notable accomplishments; however, there are still significant challenges to be addressed, namely the need to enhance the quality and efficiency of industrial development. It is imperative to recognize the interconnected nature of factors such as animal husbandry, efficiency, and environmental protection, and to formulate strategies that promote synergistic growth in these areas. Second, coordination and sharing. On the premise of ensuring food security, achieve coordinated development between planting and livestock industry is needed. This involves not only harmonizing the supply of diverse livestock products but also promoting balanced growth between the two sectors. On the premise of ensuring food security, it is important to achieve coordination between plant production and livestock production, to coordinate the supply of a variety of livestock products, and to coordinate the development of the livestock industry and the planting. In order to share the fruits of development, it is necessary to optimize the layout of livestock and plantation, to coordinate the relationship between agricultural carbon sources and sinks, and to take into account the increase in farmers’ incomes. Third, green development. The comprehensive improvement of green livestock hinges upon the optimization of breeding resources and the implementation of a green circular economy. Therefore, LHIQUD should pursue green development, taking into account the environmental quality requirements and the impact on the natural environment. Fourth, innovation and development. Innovative development is the key to break the pain points of traditional livestock industry, which could also accelerate the transformation of livestock development.

2.2.2. Evaluation System of LHIQUD

According to the definition of LHIQUD above, the evaluation index system is constructed in Table 1.

- (1) $C_i = \frac{S_i - G_i}{G_i}$, C_i refers to the coordination degree of grain and animal production. i represents the provincial or annual level, S_i refers to the grain surplus and G_i is the grain quantity used in the production of meat and eggs. Here $S_i = TG_i - TD_i$, TG_i is the total grain output and TD_i represents the grain amount used. As shown in formula, $TD_i = AU_i * UP_i + AR_i * RP_i$, AU_i and AR_i are the annual grain amount used by the urban or rural residents per capita. UP_i and RP_i are the total urban or rural population. $G_i = \sum_{j=1}^3 T_{ij} * W_j$, in the formula, T_{ij} is the product of meat and eggs as a whole, W_j is the grain discount coefficients (the grains consumed per kilogram of the meat and eggs). The Chinese Academy of Agricultural Science’s proposed ratio of meat to grain is employed as the grain conversion coefficient.
- (2) $E = \sum_{i=1}^4 e_i * q_i$, E represents carbon emissions, e_i represents the carbon emission coefficients of beef, milk, pork and egg, respectively. $e_1 = 10.16 \text{ kgCO}_2\text{-eq}$ [29], $e_2 = 1.52 \text{ kgCO}_2\text{-eq}$ [30], $e_3 = 4.29 \text{ kgCO}_2\text{-eq}$ [31], $e_4 = 3.46 \text{ kgCO}_2\text{-eq}$ [32], q_i is the output of beef, milk, pork and egg, respectively. Carbon emissions of 10 thousand yuan added value of livestock equal to total carbon emissions/added value of livestock.

Table 1. Evaluation system of LHIQUD.

Level 1	Level II	Specific Calculation Method	Indicator Attributes
Quality and efficiency improvement	Livestock labor productivity	Output value of livestock/employed persons	+
	Livestock added value per unit of water	Livestock added value/livestock water consumption	+
	Growth rate of livestock	(Current livestock product output - previous output)/previous output	+
	Improvement of livestock stations per thousand pigs, cattle and sheep	Number of improved stations/Number of pigs, cattle and sheep	+
	Green livestock certificates	Number of green food certificates × proportion of livestock products	+
Coordination and sharing	Coordination degree of grain and livestock production	Shown in Indicator interpretation (1)	-
	Share of achievements of livestock	[(Added value of livestock/local GDP) × disposable income ratio of rural-urban residents] ^{1/2}	+
	Meat Product Diversity Index	(Meat production-pork production)/Meat production	+
Green development	Ratio of total output value of livestock to agriculture	Total output value of livestock/total output value of agriculture	+
	Waste water discharge of 10,000 yuan livestock added value	Livestock wastewater discharge/livestock added value	-
	Biogas output of 10,000 yuan added value of livestock	Biogas production/value added of livestock	+
	Carbon emissions per 10,000 yuan of livestock added value	Shown in indicator explanation (2)	-
Innovation and development	Livestock machinery total power per labor	Total power of livestock machinery /employees	+
	Number of computers per hundred households in rural areas	Statistical yearbook data	+
	Percentage of graduates in livestock stations	Graduate students in livestock station/workers in livestock station	+

2.3. Data

In consideration of the connotation of LHIQUD and the availability of pertinent data, the data utilized in this study are primarily derived from statistical sources. The indexes of livestock labor and graduates in livestock stations were derived from the *China Population and Employment Statistical Yearbook* and the *China Household Survey Yearbook*, respectively. The indexes of green livestock certificates, total output value of livestock, total output value of agriculture, livestock stations, computers per hundred households in rural areas, and grain production were obtained from the *China Rural Statistical Yearbook*. The index of total power of livestock machinery is derived from the *China Agricultural Machinery Industry Yearbook*. The index of meat production is sourced from the *China Livestock and Veterinary Yearbook*. The indexes of biogas production, livestock water consumption, and wastewater treatment are obtained from the *China Environmental Statistical Yearbook*. The indexes of GDP, disposable income ratio of rural–urban residents, pesticides, fertilizers

and agricultural films by region are derived from the *China Statistical Yearbook*. Due to the absence of pertinent information in Xizang, Shanghai and Hainan, Hong Kong, Macao and Taiwan, they are not included in the study. Therefore, the study covers 28 sample provinces. It adopts the economic regional division standard of the National Bureau of Statistics, which categorizes the sample area into four major regions: the eastern, central, western, and northeastern parts. Considering factors such as livestock resource endowment, livestock advantages and disadvantages, and status in national livestock production, this study selected 28 examples to carry out studies.

3. Results

3.1. Time Dimension Analysis and Dynamic Evolution of LHIQUD

3.1.1. Time Dimension Analysis

During the research period, China's LHIQUD follows a downward tendency from the eastern and northeastern to central and western regions (Figure 1), indicating a significant regional coupling relationship with the economic zones. Temporally, LHIQUD in the four regions shows an overall upward trend, suggesting that in recent years, livestock has gradually considered quality development. The eastern region demonstrates the highest LHIQUD, reflecting a progressive advancement in environmental investment and green development. However, with the influence of environmental protection policies, the amount of livestock in this region has decreased. The eastern region also exhibits a robust economy, which confers advantages in capital and technology. Consequently, the livestock sector in the region displays a notable capacity for innovation in science, technology, and development.

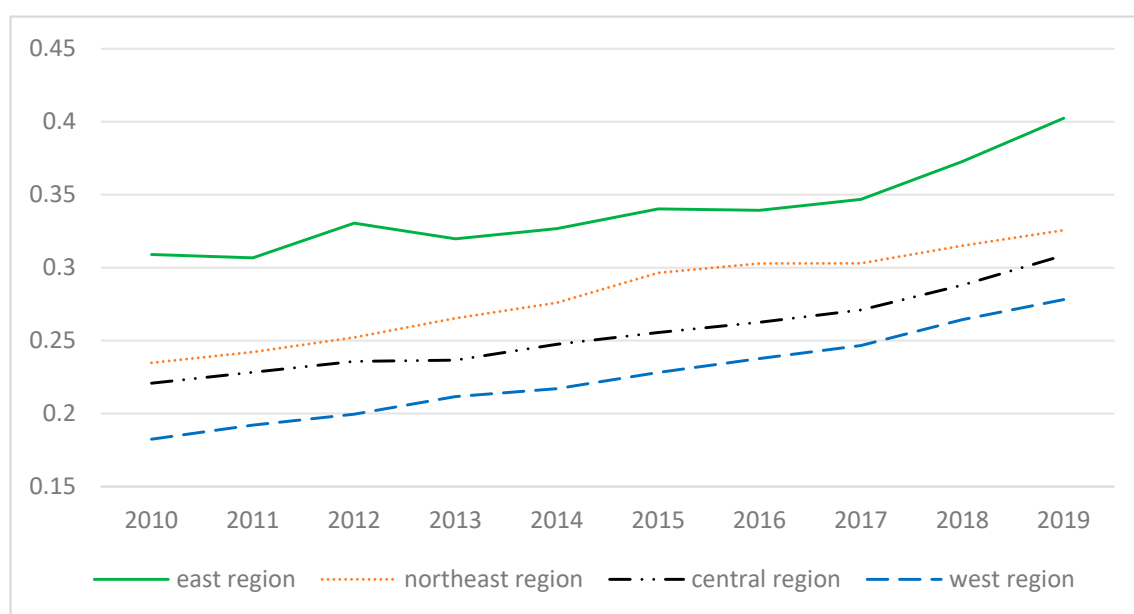


Figure 1. Evolution trend of LHIQUD.

As shown in Figure 2, during the research period, the quality and efficiency of all regions generally increased. The eastern, central, and northeastern regions took the lead alternately, far exceeding the western region. However, the western region headed the other regions with an average annual growth rate of 5%. The northeast experienced a significant decline in 2019, mainly due to the decrease in the output of livestock products and the number of certified green foods. The fluctuation range of coordinated sharing in each region was relatively small from 2010 to 2016, but it increased significantly from 2018 to

2019. Green development fluctuated upward with a range higher than that of coordinated sharing. The eastern region took the lead among other regions with an average annual growth rate of 0.6%. The growth of innovation and development was relatively large. The eastern and northeastern regions outperformed the other two regions with average annual growth rates of 6.9% and 14%, respectively.



Figure 2. Subsystem characters of LHIQUD. (a). Quality and efficiency improvement of LHIQUD. (b). Coordination and sharing of LHIQUD. (c) Green development of LHIQUD. (d) Innovation development of LHIQUD.

3.1.2. Dynamic Evolution

The LHIQUD measurement of regional livestock only reflects the changing trend temporarily. To gain further insight into the dynamic evolution process, this study employs the use of three-dimensional kernel density estimation to visualize the regional distribution of LHIQUD from 2010 to 2019, the results are shown in Figures 3–6.

The dynamic evolution trend of kernel density estimation reveals a right-shifting trend in the kernel density curves of all regions, indicating an overall upward trend during the period. From the distribution point of view, the height of the main peak in the eastern region experiences an initial increase, followed by a subsequent decline. The wave crest becomes narrow. Therefore, there seems to be a fluctuation in the levels of inter-provincial LHIQUD in the region. A reduction in the height of the main peak in northeastern China has been observed, indicating an expansion in the provincial LHIQUD difference. The height of the

central region exhibited a decrease initially, followed by an increase, while the slope of the main peak exhibited a gradual flattening, indicating that the inter-provincial difference increased initially, followed by a decrease. In the western region, the height of the main peak showed some variation, yet the amplitude was not significant, suggesting that the overall provincial fluctuation of LHIQUD was not substantial.

In examining the distribution of characters, the kernel density curve in the east and the northeast has a “right tail” phenomenon, which is mainly related to the cities with higher LHIQUD recently. In the central region, there was a narrowing of the LHIQUD differences. Furthermore, the west region exhibited an extended right tail, indicating a gradual expansion of LHIQUD.

With regard to the main peak and sub-peak characteristics, the LHIQUD in the East has a trend of multipolarization. Since 2014, it has gradually evolved into a multi-polar trend in the northeastern region. In the central region, it has experienced the evolution process from multipolar to unipolar development, while there is a multi-polar trend in the West.

The dynamic evolution characteristics of LHIQUD in different regions are affected by different factors. In recent years, the eastern region has actively promoted projects for the utilization of livestock and poultry manure resources, large-scale breeding integration, and waste treatment in the livestock industry. These efforts are designed to promote LHIQUD. Furthermore, the region has achieved notable success in the utilization of resources and LHIQUD through the establishment of a national demonstration province for green development in the livestock industry and the promotion of livestock ecological project construction. In the northeastern region, the adoption of improved seed breeding, financial support, brand building, and the strengthening of scientific and technological support systems have been instrumental in improving the degree of LHIQUD. As an important traditional farming area, the central region has successfully promoted the greening of livestock by combining planting and breeding, effectively improving feed returns and the input-output ratio. It has obvious advantages in LHIQUD in terms of improving breeding efficiency and green and circular development. The western region is striving to promote the transformation and upgrading of traditional livestock to modern high-quality livestock. The integration of modern scientific and technological methods, such as digital management and intelligent grazing, with traditional livestock practices is a significant contributor to the ongoing development of the LHIQUD in the vast pastoral areas of the west.

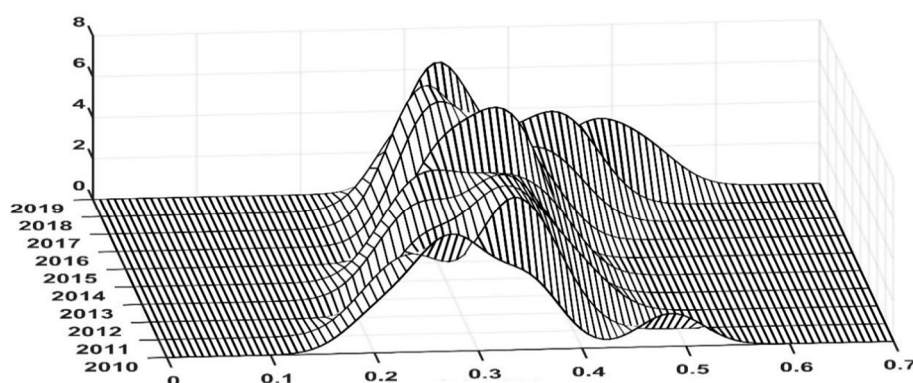


Figure 3. The kernel curve of LHIQUD in East China.

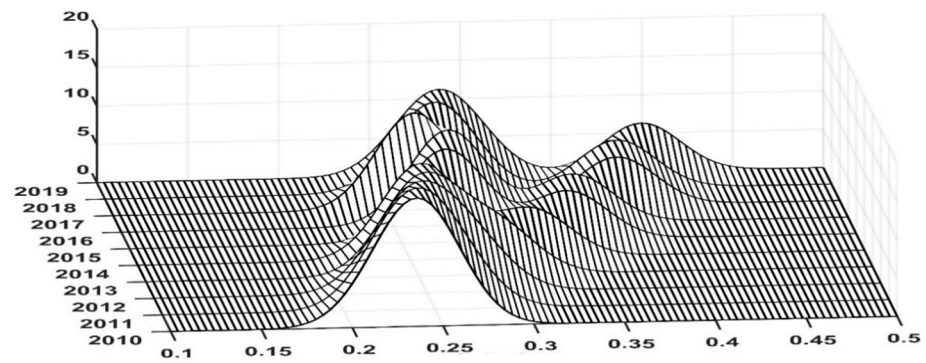


Figure 4. The kernel curve of LHIQUD in Northeast China.

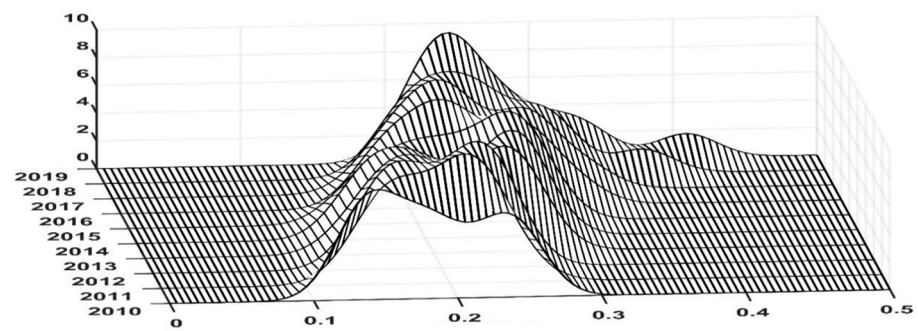


Figure 5. The kernel curve of LHIQUD in West China.

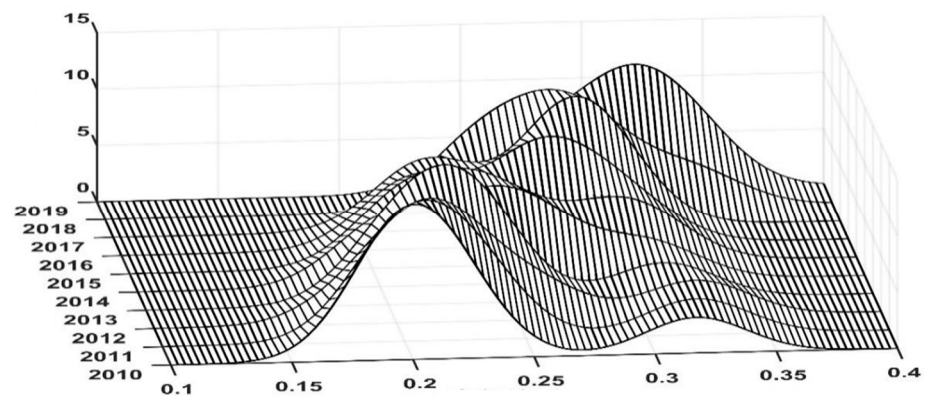


Figure 6. The kernel curve of LHIQUD in Central China.

3.2. Spatial Dimensional Analysis and Auto-Correlation Analysis of the LHIQUD

3.2.1. Spatial Dimensional Analysis

To analyze the spatial differences in LHIQUD among different provinces in China, this paper employs quartile classification, without taking into account the year. The average score of each province is divided into four tiers: low level $[0, 0.220)$, medium-low level $[0.220, 0.262)$, medium-high level $[0.262, 0.304)$, and high level $[0.304, 1]$. Overall, LHIQUD shows a positive correlation with regional economic development. Table 2 presents the classification results.

Table 2. LHIQUD classifications.

Type	High Level	Medium-High Level	Medium-Low Level	Low Level
Sample regions	Beijing, Tianjin, Hebei, Jiangsu, Zhejiang, Shandong, Shanxi, Heilongjiang	Guangdong, Inner Mongolia, Liaoning, Fujian, Henan, Chongqing, Sichuan	Jilin, Anhui, Hubei, Hunan, Guizhou, Xinjiang, Ningxia	Jiangxi, Guangxi, Yunnan, Shaanxi, Gansu, Qinghai

3.2.2. Spatial Auto-Correlation Analysis of the LHIQUD

This paper analyzes the spatial variability and auto-correlation of LHIQUD in order to gain a comprehensive understanding of its spatial characteristics, both globally and locally.

(1) Global auto-correlation analysis of the LHIQUD

The Global Moran Index for LHIQUD in China (Table 3) exhibited a positive but low overall trend, with a downward fluctuation. The areas with high or low LHIQUD exhibit a significant positive spatial correlation. That is, areas with a high LHIQUD are surrounded by similar areas. Furthermore, the weak clustering shows no obvious spatial auto-correlation of LHIQUD. In addition, there is an unstable growth trend and heterogeneous spatial clustering of LHIQUD in space and time.

Table 3. The Global Moran Index for LHIQUD.

Year	2010	2011	2012	2014	2015	2016	2017	2018	2019
Moran index	0.327	0.458	0.478	0.421	0.403	0.367	0.365	0.347	0.303
Z price	3.242	3.876	4.015	3.683	3.490	3.313	3.238	3.165	3.093
P price	0.002	0.001	0.001	0.001	0.001	0.003	0.002	0.003	0.003

(2) Local auto-correlation analysis of LHIQUD

The global spatial correlation analysis only diagnoses the cluster relationship of the spatial distribution of LHIQUD in general, while the Local Moran Index is employed to explore the inter-provincial spatial correlation. Taking 5 years as a development cycle, the Moran scatter plots of LHIQUD in 2010 (Figure 7a), 2015 (Figure 7b), and 2019 (Figure 7c) are shown below. According to Figure 7, the majority of provinces are situated in the first and third quadrants, showing interdependent and centralized features.

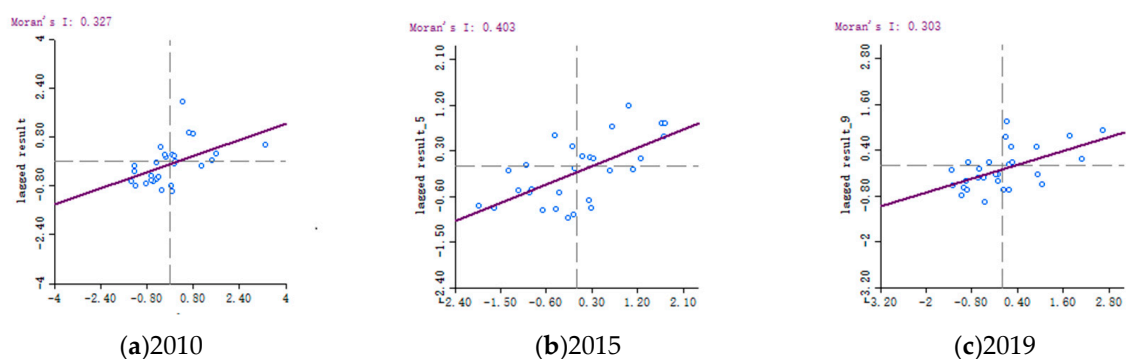
**Figure 7.** Moran scatter plots of LHIQUD.

Table 4 is the LISA agglomeration results of LHIQUD at the significance level of 10%. It shows that all regions are aggregated except the Northeast. Among the regions, the East

has a strong phenomenon of radiative forcing, while the central and western regions exhibit a comparatively weak effect.

Table 4. Cluster types of LHIQUD.

Year	H-H	L-L	H-L	L-H
2010	Beijing, Tianjin, Hebei and Jiangsu	Guangxi, Guizhou, Yunnan, Hubei, China In Hunan, Sichuan, and Xinjiang		
2011	Beijing, Tianjin, Hebei and Jiangsu	Guangxi, Guizhou, Yunnan, Hubei, China Hunan, Sichuan and Gansu		Anhui
2012	Beijing, Tianjin, Hebei and Jiangsu	Guangxi, Guizhou, Yunnan, Hubei, Hunan, Sichuan, Chongqing, Xinjiang		Anhui
2013	Beijing, Hebei, Jiangsu and Shandong	Guangxi, Guizhou, Yunnan, Hubei, Hunan, Sichuan, Chongqing, Guangdong, Xinjiang		Anhui
2014	Beijing, Hebei, Jiangsu and Shandong	Guangxi, Guizhou, Yunnan, Hunan, etc. Guangdong, Sichuan, and Xinjiang	Chongqing	Anhui
2015	Beijing, Tianjin, Hebei and Jiangsu	Guangxi, Guizhou, Yunnan, Hunan, etc. Sichuan, Xinjiang	Guangdong	Anhui
2016	Hebei, Shandong, and Jiangsu provinces	Sichuan, Yunnan, Guizhou, Guangxi, China Gansu, Xinjiang	Guangdong, Chongqing	Anhui
2017	Hebei, Shandong, Jiangsu and Anhui	Guangxi, Guizhou, Yunnan, Gansu and Xinjiang	Sichuan, Guangdong, Chongqing	
2018	Shandong, Jiangsu, Zhejiang and Anhui	Guangxi, Guizhou, Yunnan and Hunan	Sichuan, Guangdong, Chongqing	
2019	Beijing, Hebei, Jiangsu, Shandong, Jiangsu, Zhejiang, Anhui	Xinjiang, Gansu, Guangxi and Ningxia	Guangdong, Sichuan	

In the ‘high-high’ area, there are Beijing, Tianjin, Hebei, Shandong, Jiangsu, and Zhejiang, mainly in the East, presenting features of zonal distribution and clustering. They mainly rely on the advantages of green and innovative development, with the annual growth rate of 6.9%, to promote LHIQUD. The radiation effect serves to drive the LHIQUD in the surrounding provinces. Considering the ongoing promotion of integrated growth in the Beijing–Tianjin–Hebei region, new measures are continuously being introduced with a view to fostering scientific and technological innovation, green development, and the sharing of information on livestock.

In the ‘low-low’ area, there are Guizhou, Guangxi, Yunnan, Hunan, Ningxia, Gansu, and Xinjiang, mainly in the western and central regions with the characteristics of stripe distribution and clustering. The level of mechanical power in livestock in the two regions is relatively low, only 32–45% of that in the northeast. In addition, the proportion of highly educated talents in the central region and the information level in the western region lag behind other regions by 23–31%. These provinces and their surrounding provinces exhibit a relatively low level of LHIQUD, lacking the capacity for radiation-driven advancement.

Chongqing, Guangdong, and Sichuan have successfully undergone a transformation from a ‘low-low’ to a ‘high-low’ area. Relying on regional economic development advan-

tages, Guangdong has continuously increased investment in science and technology by 3% annually, actively promoting the LHIQUD. Chongqing and Sichuan represent the primary development areas for pig production in China, accounting for approximately 10.45%. However, as a consequence of the outbreak of the African Swine Fever, Chongqing was removed from the 'high and low' area in 2019. Although the livestock development in these regions has achieved certain development, the LHIQUD in the surrounding provinces remains relatively low. It is therefore evident that they could serve as a conduit for the dissemination of information, thereby facilitating the establishment of a seamless communication network and the subsequent promotion of the LHIQUD in the surrounding provinces. In the 'low-high' area, Anhui is geographically proximate to Shandong and Jiangsu, which possess distinctive advantages in livestock production. The strong radiation effects observed in these provinces have contributed to the continued improvement of LHIQUD, with a steady transition from the 'low-high' area to the 'high-high' area.

4. Discussion

In summary, the degree of LHIQUD in China has been decreasing in the eastern, northeastern, central, and western regions. The development of four major economic zones has a significant geographic coupling relationship with LHIQUD. This conclusion is similar to the findings of Xiong [13], Gu [19], and Wang [33]. LHIQUD is positively related with economic development. LHIQUD is concentrated in economically developed areas, where many provinces have a high level of livestock production. In contrast, provinces with low LHIQUD are mainly distributed in economically less developed areas. This conclusion is consistent with the findings of Xin [16], Li [17], and Lu [18]. However, this study proposes that LHIQUD's degree in the western region evolves from unipolarization to multipolarization, which is slightly different from the conclusion of the study of unipolarization in the western region drawn by Xiong. There may be two main reasons for this: first, the different focuses of the design of the evaluation system of LHIQUD; second, compared with Xiong's study, the present study selects a more recent sample time period, and the results reflect the unipolarization process proposed in his study. Additionally, in recent years, the western region has implemented various measures to enhance the quality and efficiency of livestock development, moving towards multipolarization.

5. Conclusions and Suggestions

5.1. Conclusions

Based on the connotation of livestock LHIQUD, the study constructs the evaluation system of LHIQUD. It evaluates the livestock LHIQUD of China over the last ten years and analyzes the dynamic evolution and spatial correlation. It could be argued that the following points represent the primary conclusions:

First, there appears to be a decreasing trend in the LHIQUD degree as moving from the eastern, northeastern, central, to western regions. According to the temporal characteristics, the four regions have shown a general upward trend with an average annual growth rate of 3–5%, indicating that the livestock development of China has achieved initial results. The quality and efficiency of all regions generally increased. The eastern, central, and northeastern regions took the lead alternately, far exceeding the western region. However, the western region led the other regions with an average annual growth rate of 5%. The northeast experienced a significant decline in 2019. The fluctuation range of coordinated sharing in each region was relatively small from 2010 to 2016, but it increased significantly from 2018 to 2019. Green development fluctuated upward with a range higher than that of coordinated sharing. The eastern region took the lead among other regions with an average

annual growth rate of 0.6%. The eastern and northeastern regions outperformed the other two regions with average annual growth rates of 6.9% and 14%, respectively.

Second, interprovincial differences in LHIQUD are characterized by spatial imbalance. The East shows a trend of shrinking first and then increasing, while the northeast shows a trend of expansion, and the central and western regions change alternately between expansion and contraction. The LHIQUD in the central region turns from multipolarization to unipolarization, while other regions show a multipolarization trend.

Third, LHIQUD degree is positive related to economic development. Nearly 30% of high-degree provinces are concentrated in economically developed areas, where many provinces have a high level of livestock production. In contrast, provinces with a low degree of LHIQUD, accounting for 40%, are mainly distributed in economically less developed areas.

Fourth, the spatial auto-correlation of livestock LHIQUD in China is not very obvious. There is a weak agglomeration pattern in general, but the growth trend shows instability temporally and spatially. Provincial livestock LHIQUD is interdependent and agglomerate in the geographical space.

5.2. Suggestions

Based on the conclusions of the above studies, the following policy recommendations are proposed in order to effectively promote the LHIQUD.

First, stimulating the quality and efficiency of livestock by enhancing the livestock breeding system with high-quality products. Rationalizing the layout of livestock breeding and improvement sites. The promotion of large-scale breeding, standardized production, and supervision will improve the quality and safety inspection and testing systems of livestock products and cross-regional information tracing platforms. Furthermore, it is advisable to focus on building the brands of enterprises and green livestock products that are superior in each region, while also improving quality and efficiency.

Second, promoting innovation in livestock, including scientific, technological, operational and financial aspects. It is imperative to reinforce the fundamental theoretical framework, research and development of key technologies and cultivation of major new varieties. Furthermore, it is crucial to devise innovative operational models and prioritize internationalization, industrialization, and collaboration in the advancement of livestock. Additionally, it is essential to enhance credit support and risk management and encourage the influx of social capital into the livestock industry.

Third, improving coordination and sharing in livestock development by unblocking information and resources, raising farmers' incomes, and optimizing the industrial structure of livestock. The advantages of a region's resource endowment can be leveraged to facilitate the development of less developed regions through the livestock industry. This approach can help to narrow the gap between the development of regional livestock. The optimization of livestock species structure and land for farming, as well as the incentive policy for transferring cattle and sheep out of large counties, can meet the increasing demand for meat consumption structure of urban and rural residents. Narrowing the gap between the income levels of farmers in different regions improves the farmers' sense of belonging, identity, and pride, and ultimately promotes the sharing of the fruits of the high-quality development of the livestock industry by the farmers.

Fourth, enhancing green development of livestock through energy saving, emission reduction, and waste recycling by scientifically calculating the carbon emissions in livestock, actively promoting the research and development of low-carbon technologies, and breeding waste recycle. Furthermore, the utilization of manure resources from livestock and poultry

is actively encouraged in various livestock regions across the country. Ultimately, the objective is to reduce the emissions from livestock, achieving the goal of “double carbon”.

Fifth, a range of measures should be implemented in accordance with the regional characteristics of high-quality development in the livestock industry. The eastern region is advised to focus on increasing production and the northeastern region is encouraged to initiate measures to improve the management of animal waste. The central region is recommended to prioritize the development of low-carbon and environmentally sustainable livestock products, and the western region is advised to adopt advanced livestock technology. The region demonstrates a superior level of high-quality development in the livestock industry and is identified as a potential catalyst for promoting the advancement of regions experiencing lag, through the provision of advanced technology, skilled technicians, and low-carbon equipment.

Due to the limitation of data availability, the evaluation of high-quality development of animal husbandry in this paper is chiefly based on empirical studies of 28 provinces in China in the last decade. Subsequent studies can expand the time frame and refine the spatial scope of the study to examine the medium and long-term high-quality development of the national livestock industry and the high-quality development of the livestock industry in various cities and regions. The establishment of a comprehensive research system is recommended to promote livestock sustainability.

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