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A Study on the Measurement of Agricultural Value Chain Participation Based on the TOPSIS Method

Yilin Zhong[1], Yingsheng Li[2*], and Lianfen Huang[2]

[1]School of Economics and Management, China Agricultural University, China

[2]School of Informatics, Xiamen University, Xiamen, China
1553423330@qq.com, liyingsheng@stu.xmu.edu.cn, lfhuang@xmu.edu.cn

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Abstract. In the context of globalisation, the agricultural value chain has emerged as a pivotal component. This research focuses on examining the role and impact of the agricultural value chain, utilizing the entropy-weighted technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Through comprehensive analysis, this study aims to identify key trends, clustering patterns, and future directions in the agricultural value chain's development within the globalised economy.

Keywords: agricultural value chain, entropy-weighted, TOPSIS, globalisation

1 Introduction

In the context of globalisation, the agricultural value chain has become a crucial link in connecting the economies of different countries. This study addresses issues like the efficiency and equity in the agricultural value chain, the effect of agriculture on climate change, adaptation strategies to climate change, the sustainability of agriculture, the relationship between agriculture and economic development, and how the agricultural value chain affects the economic development of various countries, by accurately measuring the positions and participation level of different countries in the agricultural value chain. The evaluation and optimisation of agricultural value chains across countries has long been a research hotspot and also a challenge. Typically, traditional agricultural efficiency evaluation methods only work with single indicators or simplistic composite measures, which do not completely reflect those smart agricultural systems. This study therefore proposes the entropy-weighted TOPSIS method, to supply more methodologically sound and accurate support for determining the evaluation of agricultural value chain among countries.

2 Measurement and Evaluation of Agricultural Value Chain Participation

2.1 Overview of Value Chain Measurement Methods

Recently, substantial progress has been made in measuring the position of countries in global value chains, with important results. The concept of vertical specialisation and the measure of it, by the ratio of foreign value added to export value, was first introduced by Hummels [1] in 2001. This method was not usable for computing domestic value-added, because of data limitations. In 2007, Hausmann [2] proposed using technical complexity as an indicator to examine a country's position in the global value chain. However, this indicator, based on total trade volume, cannot identify whether high-tech production stages of exported products are completed domestically. In 2008, Koopman [3] used Input-Output Tables (ICIO tables) between countries to propose a method for measuring domestic value added, addressing the shortcomings of Hummels' method. Later, in 2010, Koopman [4]

* Corresponding Author

established two indicators: the global value chain participation rate and the global value chain position index, and argued that the combination of these two indicators could more accurately locate a country's role in the global value chain division of labour. This study employs Koopman's methodology to assess global agricultural value chain data.

2.2 Measurement of Agricultural Value Chain Participation

This study explores the agricultural value chain across countries using relevant indicators from the World Bank's statistics, such as livestock production indices, agricultural, forestry, and fishery value-added, and the imports and exports of agricultural raw materials. Most existing research on global agricultural value chains has focused on the macro level, with relatively limited application of new technologies and methodologies at the micro level.

This study draws upon academic literature in agricultural economics, supply chain management, industrial organization, machine learning, data mining, and big data analysis, as well as research reports and policy documents on agricultural value chains published by international organizations and government agencies, to provide comprehensive and in-depth insights. Building on existing research and authoritative databases, the study employs methods such as TOPSIS and machine learning techniques, with the goal of analysing agricultural value chains at the micro level. By combining these innovative machine learning approaches, the study aims to offer a more detailed analysis of agricultural value chains between countries, identify existing challenges and opportunities for optimisation, and provide new insights and methods for improving agricultural value chains.

2.3 Agricultural Value Chain Evaluation Method Based on Entropy-Weighted TOPSIS

Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making technique. The basic principle is that data of each evaluation indicator is plotted in a coordinate system, and the best (optimal) and the worst (least favourable) solutions are identified, from which the Euclidean distance of each evaluation alternative from the most ideal solutions is calculated. The performance of each alternative is then measured by the level of its proximity to the optimum or worst ideal solution. However, unlike methods such as fuzzy comprehensive evaluation, expert surveys and multiple data sources are needed, meaning that data collection is comparatively difficult. Analytic Hierarchy Process (AHP) is based on score assignments by experts, based on different criteria, that is, subjectivity is brought into the process. In addition, the grey relational analysis method sometimes uses weighted assignment subjectively and normally uses smaller datasets. These rationales motivated this study to select the more accurate and integrated entropy-weighted TOPSIS method.

This study uses the TOPSIS method to determine the country's position and level of participation in the agricultural value chain. Weights for different indicators are obtained by the entropy weighting method, and then a comprehensive evaluation score for agricultural value chain participation is calculated.

This study also examines 67 different countries, such as China, India, and Japan, and evaluates them within six dimensions–global value chain participation rate; crop production index etc. The evaluation and analysis of these countries is based on 18 indicators.

Let there be m countries and n indicators, forming the initial matrix X, where $x_{i,j}$ represents the value of the j indicator for the i country. First, each indicator is standardised. Then, the entropy-weighting method is applied to calculate the weights of each evaluation indicator. Finally, the TOPSIS method is used to determine the evaluation scores.

(1) Standardise the Initial Matrix

The initial matrix $X = (x_{ij})_{m\times n}$ is standardised to obtain the standardised matrix Z_{ij} ;

$$Z_{ij} = \begin{cases} \dfrac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, x_{ij} \textit{ is Positive indicator} \\ \dfrac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, x_{ij} \textit{ is Negative indicator} \end{cases} \quad (1)$$

(2) Calculate the information entropy of the j indicator e_j ;

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m}\left(\frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}}\right)\cdot \ln\left(\frac{Z_{ij}}{\sum_{i=1}^{m} Z_{ij}}\right) \quad (2)$$

(3) Calculate the weight of the j indicator W_j ;

$$W_j = \frac{1-e_j}{\sum_{j=1}^{n}(1-e_j)} \quad (3)$$

(4) Construct the weighted normalized matrix T ;

$$T_{ij} = W_j Z_{ij} \quad (4)$$

(5) Solve the positive ideal solution t^+ and the negative ideal solution t^- ;

$$t^+ = \left(t_1^+, t_2^+, \cdots, t_n^+\right) = \left\{\max t_{ij} \mid i = 1, 2, \cdots m\right\} \quad (5)$$

$$t^- = \left(t_1^-, t_2^-, \cdots, t_n^-\right) = \left\{\min t_{ij} \mid i = 1, 2, \cdots m\right\} \quad (6)$$

(6) Calculate the distances of each value chain D_i^+ and D_i^- ;

$$D_i^+ = \sqrt{\sum_{j=1}^{n}\left(t_{ij} - t^+\right)^2} \quad (7)$$

$$D_i^- = \sqrt{\sum_{j=1}^{n}\left(t_{ij} - t^-\right)^2} \quad (8)$$

(7) Calculate the comprehensive evaluation value C_i ;

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (9)$$

Where $0 \le C_i \le 1$, the larger the value of C_i , the smaller the Euclidean distance between the evaluation indicator and the positive ideal solution t^+, indicating better performance of the evaluation target, and more developed agriculture in that country. Conversely, the smaller the value of C_i , the smaller the Euclidean distance between the evaluation indicator and the negative ideal solution t^-, indicating worse performance of the evaluation target, and underdeveloped agriculture in that country.

3 Analysis of TOPSIS Agricultural Value Chain Evaluation Results

In this study, 67 countries were selected, and their comprehensive evaluation scores were calculated according to the formulas. An indicator system was established, as illustrated in Fig. 1.

Fig. 1. Agricultural value chain participation measurement indicator system

Table 1 presents the research aimed at measuring international agricultural value chain participation, through indicators such as global value chain participation rate, agricultural, forestry, and fishery value chain participation rate, crop production index, agricultural raw material imports and exports, agricultural and forestry value-added, and agricultural land use. These indicators are analysed together with the degree of reference to forward and backward participation in the global value chain, division of labour, livestock and crop production indices, rural electricity supply, and rural population and employment, as well as their types and weight distribution analysis.

Fig. 2 illustrates the distribution of weight for international agricultural value chain reference and measurement. It is visible that the grain production index and crop production index are influential, whereas the livestock production index has less impact on the overall evaluation. It is also evident that the agricultural, forestry, and fishery global value chain, backward participation and the division of labour position in the global value chain are key factors that significantly affect the entire evaluation system. From the global value chain perspective, forward participation encompasses the majority of the global value chain information. In terms of agricultural, forestry, and fishery value-added, both the proportion of agricultural, forestry, and fishery value-added to GDP, and the proportion of agricultural, forestry, and fishery value-added in USD are critical indicators for measuring agricultural value chain participation. Fig. 2 shows that the indicator representing the proportion of agricultural, forestry, and fishery value-added to GDP has the highest weight, while the proportion of agricultural, forestry, and fishery value-added in USD ranks third. From the perspective of agricultural land use, agricultural electricity supply is less significant, compared to agricultural population and employment in rural areas. Regarding agricultural imports and exports, analysing agricultural raw material exports provides more valuable information than analysing imports.

Table 1. International agricultural value chain reference and measurement research

Objective layer	Normative layer	Indicator layer	Indicator layer	Weight
International Agricultural Value Chain Participation Measurement Research	Global Value Chain Participation	Global Value Chain Forward + Backward Participation	+	1.747
		Global Value Chain Forward Participation	+	3.515
		Global Value Chain Backward Participation	-	1.429
		Global Value Chain Position in Division of Labor	+	2.188
	Agricultural, Forestry, and Fishery Value Chain Participation	Agricultural, Forestry, and Fishery Forward + Backward Participation	+	1.687
		Agricultural, Forestry, and Fishery Forward Participation	+	1.116
		Agricultural, Forestry, and Fishery Backward Participation	-	5.475
		Agricultural, Forestry, and Fishery Position in Division of Labor	+	6.561
	Production Index	Livestock Production Index	+	0.626
		Grain Production Index	+	3.024
		Crop Production Index	+	3.044
	Agricultural Raw Material Import and Export	Agricultural Raw Material Imports	-	1.206
		Agricultural Raw Material Exports	+	14.478
	Agricultural, Forestry, and Fishery Added Value	Agricultural, Forestry, and Fishery Added Value (Current USD)	+	37.118
		Agricultural, Forestry, and Fishery Added Value (As Percentage of GDP)	+	11.475
	Agricultural Land Use	Rural Electricity Supply (As Percentage of Rural Population)	+	0.99
		Rural Population (As Percentage of Total Population)	-	2.136
		Agricultural Employment	-	2.184

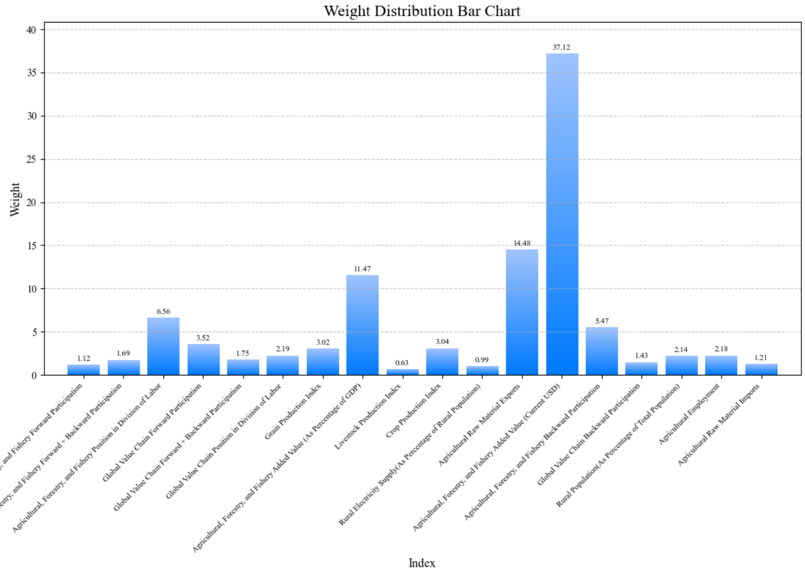


Fig. 2. Bar chart of international agricultural value chain reference and measurement weight distribution

In the comprehensive evaluation system presented in Fig. 3, the greater the weight of an indicator, the more significant its influence on the evaluation results. China and India ranked first and second in this evaluation, primarily due to the relatively high net economic value generated by these two countries in their production processes. Although the value of agriculture, forestry, and fisheries in the United States is relatively high in dollar terms, the proportion of agriculture in U.S. GDP is relatively small, while China and India have higher values in other aspects.

The measurement and evaluation of agricultural value chain participation is still in its early stages, and no unified evaluation standard exists. Due to the many and complex factors influencing the agricultural value chain, it is necessary to consider the specific circumstances of each country. Figure 4 presents a schematic diagram of the international agricultural value chain participation evaluation, using a standard deviation classification method. The classification is as follows; $0 < C \leqslant 0.2537$ (low); $0.2537 < C \leqslant 0.3510$ (medium); $0.3510 < C \leqslant 0.3997$ (high); and $0.3997 > C$ (very high).

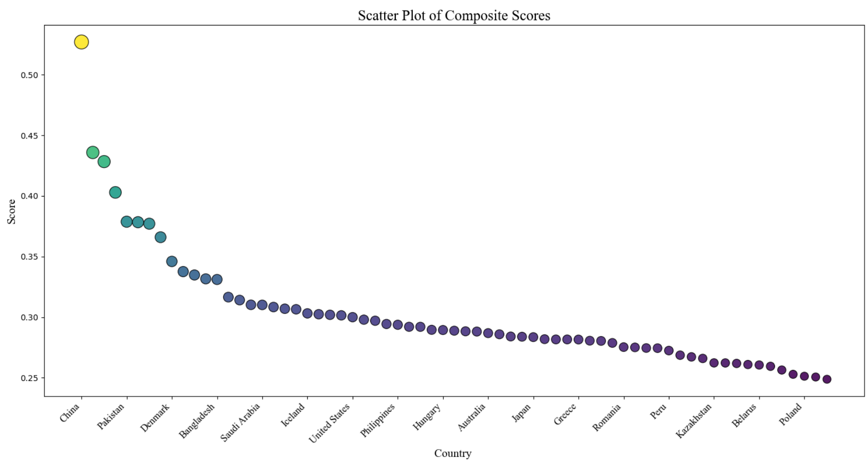
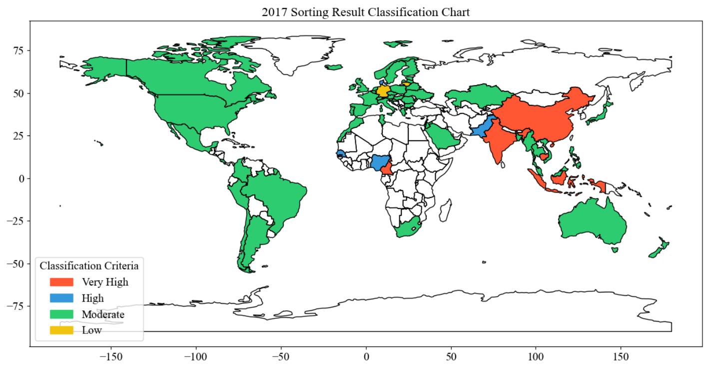
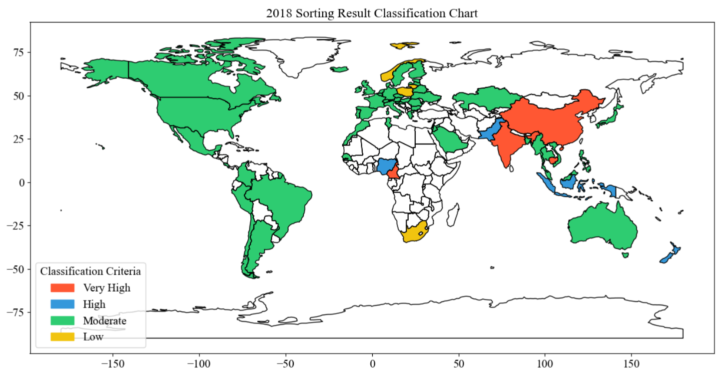


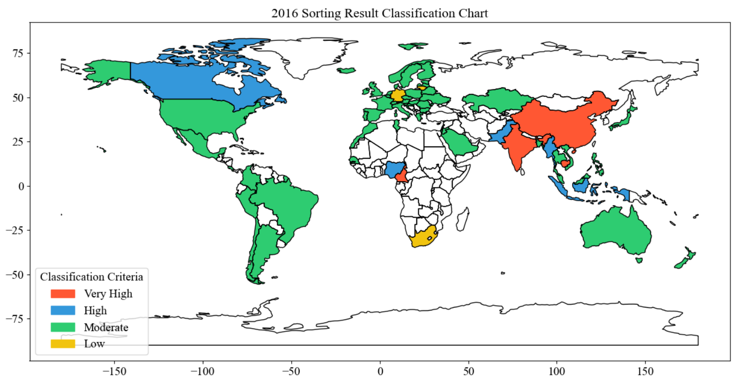
Fig. 3. Comprehensive national evaluation system



(a) Classification of international agricultural value chains (2017)



(b) Classification of international agricultural value chains (2018)



(c) Classification of international agricultural value chains (2016)

Fig. 4. Agricultural value chain participation measurement evaluation

Through a three-year comparison, as shown in Fig. 4(a), Fig. 4(b) and Fig. 4(c), it can be observed that China, India, Cameroon, and Cambodia have sustained a relatively high level of agricultural development over the past three years. Cameroon, located in Central Africa, possesses favourable natural resources and climate conditions. From the perspective of the agricultural value chain, Cameroon is one of the world's most important producers of cocoa and coffee, with significant exports, mainly to European markets. The data shows that Cameroon ranks among the top exporters among the 67 countries analysed. Cambodia also has a high proportion of agricultural, forestry, and fishery sectors in its GDP, demonstrating the country's strong focus on agriculture. Moreover, Cambodia's government has prioritised agriculture as a key sector for achieving economic diversification and poverty reduction in its national development plan for 2015-2030.

This study employs the entropy-weighted TOPSIS method to measure agricultural participation, which eliminates the subjectivity inherent in the weight-setting process. This enables a more objective reflection of the dynamic trends in agricultural participation measurement across countries.

3.1 Model Rationality

Rationality of Indicators: All data in the model has been standardised, and positive and negative indicators have been assigned according to actual conditions. The key indicators in the model, such as agricultural, forestry, and fishery value-added, as well as imports in these sectors, show significant variation due to large differences in the data across countries. As a result, these indicators are assigned higher weight, as agricultural, forestry, and fishery sectors are crucial components of the agricultural value chain system.

Rationality: The weight in the model shows clear distinctions, with high differentiation. Countries ranked at the top have relatively strong agricultural economic foundations, and this aligns with the results produced by the model.

Robustness: When the weights of indicators like agricultural, forestry, and fishery value-added in GDP, agricultural, forestry, and fishery value-added in USD, and agricultural raw material exports are randomly adjusted, the rankings remain largely unchanged, as shown in Fig. 5.

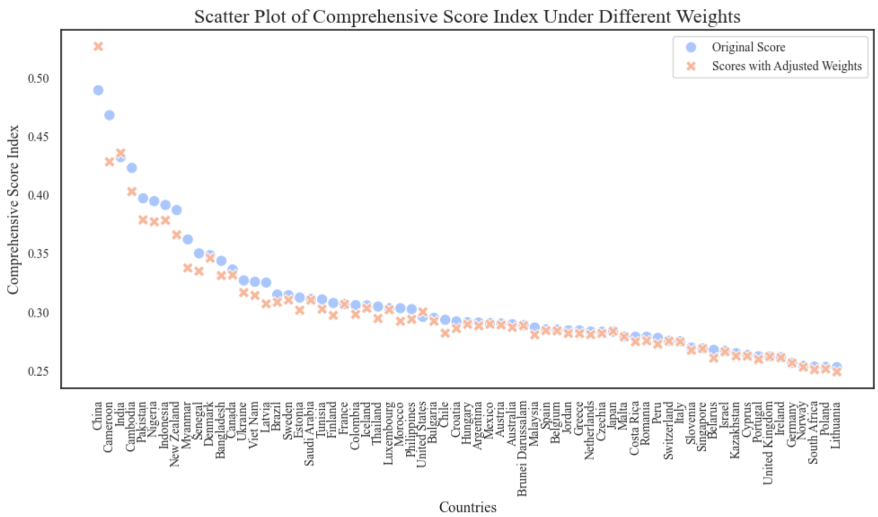


Fig. 5. Comprehensive evaluation score index of national agricultural value chain participation

Correlation: The independence of each indicator is well-maintained, with no redundancy among the indicators. The heatmap, shown in Fig. 6, illustrates this.

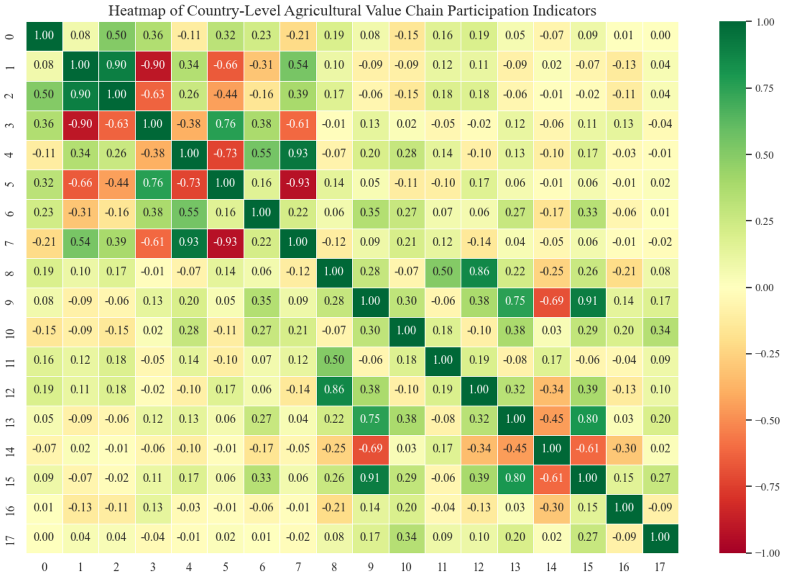


Fig. 6. Heat map of agricultural value chain participation measurement indicators

Applicability: The entropy-weighting method analyses objective data, while the TOPSIS method calculates the distance between the data and both the positive and negative ideal solutions. The results are intuitive and provide an objective evaluation.

4 Conclusion

4.1 Research Conclusions

Global Agricultural Value Chain Participation and Division of Labour. China plays a significant role in the global agricultural value chain. However, compared to some developed countries, such as Norway, China still needs to strengthen its efforts in agricultural product deep processing and brand development. Moreover, China needs to further optimise its position in the global value chain division of labour to enhance agricultural production efficiency and added value.

Land Preparation and Management. China faces the challenge of insufficient arable land, which limits the potential for agricultural growth. However, if China can learn the lessons from countries such as Russia, and put land to better use, as well as promote advanced agricultural technology, it can overcome this challenge.

4.2 Reflection on Research Conclusions

The Importance of Sustainable Agricultural Development. With global climate changes, and decreasing resources such as land, water, energy and mineral resources, sustainable agricultural development has become an urgent problem. Thus, more attention on the part of governments and society should be placed on environmental protection and sustainability. Agriculture needs to develop towards greener low carbon and circular agriculture. Being one of the world's largest agricultural producers, China should pay more attention to the sustainability of agricultural production that promotes organic farming, reduce the use of fertilizers and pesticides, and protect the ecological environment, to guarantee the long-term stability of agricultural development.

Promoting Agricultural Technological Innovation. Improving agricultural production efficiency and quality is largely dependent on agricultural technological innovation. China can augment investments in agricultural research and development, and foster enterprise co-operation with universities and research institutions, leading to agricultural technology innovation and upgrading. Meanwhile, the government should also formulate support policies to encourage the transformation and application of new agricultural technological achievements, and promote modernisation and digital transformation in agricultural production.

Optimizing the Global Agricultural Value Chain. With modern globalisation, more and more countries are co-operating with agricultural development. Countries should improve co-operation and exchange of agricultural value chain research. Research outcomes and experiences should be shared, and collaborative development of the global agricultural value chain should be promoted. China should actively take part in the building and optimisation of the global agricultural roundabout chain, creatively co-operating with countries upstream and downstream, to reach the most optimum resource allocation. In addition, China should further promote its place and influence in the international agricultural value chain, and play a more positive role in the global production of agricultural products.

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