Postprint: Agricultural Circular Economy Evaluation and Obstacle Factor Analysis Based on IUPCE

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Abstract

To clarify the development level and obstacle factors of agricultural circular economy in Jiangxi Province from 2000 to 2015, this study, based on the agricultural production input-utilization-output-consumption-effect (IUPCE) process, selected data of 20 evaluation indicators across 5 categories from the 2001-2016 statistical yearbooks, employed the entropy method to determine indicator weights for calculating the development level of agricultural circular economy, and utilized three metrics—factor contribution degree, indicator deviation degree, and obstacle degree—to diagnose its obstacle factors. The results show that: (1) During 2000-2016, the development levels of utilization indicators, output indicators, consumption indicators, and effect indicators of agricultural circular economy in Jiangxi Province all demonstrated an overall upward trend, with the magnitude of increase being output indicators > effect indicators > consumption indicators > utilization indicators, while input indicators showed a downward trend; (2) The growth of agricultural circular economy in Jiangxi Province from 2000 to 2015 exhibited an overall upward trend, with an average annual growth rate of 3.43%, indicating relatively slow growth; (3) During 2000-2008, the main obstacle factors affecting the development of agricultural circular economy in Jiangxi Province included fertilizer effective utilization coefficient, fertilizer use intensity, per capita cultivated land, forest coverage rate, and per capita net income of farmers; during 2009-2015, the main obstacle factors were fertilizer use intensity, multiple cropping index, effective irrigation coefficient, and crop sowing area; (4) From 2000 to 2015, input indicators and utilization indicators were the primary obstacle factors affecting the development of agricultural circular economy in Jiangxi Province, with the obstacle degree values of input indicators and utilization indicators showing a gradually increasing trend, while the obstacle degree values of output indicators, consumption indicators, and effect indicators demonstrated an overall decreasing trend.

Full Text

Evaluation and Analysis of Barrier Factors in Agricultural Circular Economy Based on IUPCE: A Case Study of Jiangxi Province

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Abstract

To clarify the development level and obstacles of agricultural circular economy in Jiangxi Province from 2000 to 2015, this study constructed an evaluation framework based on the Input-Utilization-Output-Consumption-Effect (IUPCE) process of agricultural production. Using statistical yearbook data from 2001–2016, we selected 20 evaluation indicators across five categories and employed the entropy method to determine indicator weights and calculate the development level of agricultural circular economy. We further diagnosed barrier factors using three metrics: factor contribution degree, index deviation degree, and obstacle degree. The results show that: (1) From 2000 to 2016, the utilization, output, consumption, and effect indices of Jiangxi' s agricultural circular economy all showed upward trends, with the output index increasing most rapidly, followed by the effect index, consumption index, and utilization index, while the input index showed a downward trend; (2) The overall agricultural circular economy growth in Jiangxi from 2000 to 2015 exhibited an upward trend with an average annual growth rate of 3.43%, indicating relatively slow growth; (3) The main obstacle factors affecting Jiangxi' s agricultural circular economy development during 2000–2008 were the effective utilization coefficient of chemical fertilizers, fertilizer use intensity, per capita arable land, forest coverage rate, and per capita net income of farmers, while during 2009–2015 they were fertilizer use intensity, multiple cropping index, effective irrigation coefficient, and crop sown area; (4) Input and utilization indicators were the primary obstacles affecting Jiangxi's agricultural circular economy development from 2000 to 2015, with their obstacle degree values showing a gradual increasing trend, while the obstacle degree values of output, consumption, and effect indicators generally decreased.

Keywords: Agricultural Circular Economy; Entropy Method; Factor Contribution Degree; Index Deviation Degree; Barrier Degree

Introduction

Circular economy represents the optimal pathway for improving environmental quality, enhancing comprehensive resource utilization, and addressing sustainable development challenges, as well as an effective approach for coordinating China' s economic, social, and ecological development. Chinese agriculture currently faces issues of high resource consumption, high pollution emissions, and low utilization of materials and energy, which will ultimately lead to agricultural resource depletion and ecological environment degradation—problems that must be resolved through circular economy principles. Jiangxi Province, a traditional agricultural province in China with abundant agricultural resources and prominent ecological advantages, has over 80% of its population engaged in agriculture. However, Jiangxi's agricultural development suffers from serious non-point source pollution, low land resource utilization efficiency, and insufficient awareness of the importance and necessity of developing circular agriculture. Therefore, in-depth investigation into the evaluation of agricultural circular economy development and its barrier factors in Jiangxi Province is crucial for clarifying the current status of circular economy development, improving resource utilization efficiency, and preventing and controlling environmental pollution.

Agricultural circular economy has long been a hot research topic among scholars. Different evaluation indicator systems for circular agriculture vary in composition depending on their service objectives and targets. Existing literature primarily focuses evaluation at the macro level, including studies on China, Jiangsu, Hebei, Heilongjiang, Henan, Hubei, Guangdong, Ningxia, Hunan, Jilin, Sichuan, and various river basins. Some research also examines circular agricultural development models at the micro level. Evaluation indicator systems for agricultural circular economy development can be divided into two categories: (1) Macro-level comprehensive evaluations for national, provincial, and basin-wide agricultural circular economy, primarily based on the "3R" principles (reduce, reuse, recycle) to assess social, economic, and ecological benefits through indicators of economic and social development, resource reduction input, resource recycling, and resource-environment security, using methods such as projection pursuit classification models, analytic hierarchy process, osculation value method, grey correlation analysis, principal component analysis, and emergy analysis. Some studies employ DEA methods from an input-output perspective to evaluate agricultural circular economy efficiency; (2) Micro-level assessments of ecological and economic benefits of circular industries and agricultural development models, commonly using life cycle assessment, emergy analysis, and system dynamics models. Research on factors affecting agricultural circular economy development falls into two categories: analyses of internal factors based on macro-level data, typically using "factor contribution degree," "index deviation degree," and "obstacle degree" to diagnose main obstacles, and analyses of external factors based on micro-survey data, often using structural equation models.

In summary, existing research provides a theoretical foundation for further analysis. However, most studies construct indicators based on the "3R" principles, neglecting the impact of rural residents' consumption on agricultural circular economy, and few focus on Jiangxi Province. Therefore, this study incorporates rural residents' consumption indicators based on previous research, constructs input, utilization, output, consumption, and effect indicators according to the agricultural production IUPCE process, evaluates Jiangxi' s agricultural circular economy development from 2000 to 2015, and conducts empirical analysis of internal factors hindering agricultural circular economy development.

1.1 Basic Content of Evaluation

Agricultural circular economy is an economic development model that reduces resource and material inputs, increases material recycling and multi-level energy use, decreases waste generation and emissions, and achieves win-win outcomes for agricultural economy, ecological environment, and social benefits throughout agricultural production processes and product life cycles. Based on this connotation, this study constructs an Input-Utilization-Output-Consumption-Effect (IUPCE) conceptual model [Figure 1: see original paper] to evaluate agricultural circular economy development. Unlike general agricultural input-output processes, circular agriculture involves material and resource inputs that, through recycling and reuse, generate economic and social benefits, promote rural residents' consumption, and consequently impact external resources and environment. Solid lines in the model represent circular agriculture processes, while dashed lines represent influence processes, wherein input, utilization, and output stages also affect the effect stage, and the consumption stage influences all other stages.

This study evaluates agricultural circular economy development from two perspectives: (1) Based on analysis of agricultural status quo, selecting evaluation indicators reflecting regional agricultural development realities, using the entropy method to determine indicator weights, constructing a comprehensive evaluation indicator system, and conducting overall evaluation of Jiangxi' s agricultural circular economy; (2) Diagnosing obstacle factors through three metrics—factor contribution degree, index deviation degree, and obstacle degree—to identify main constraints on regional agricultural circular economy development and provide information for promotion [Figure 2: see original paper].

1.2 Evaluation Indicator Selection

Based on understanding of agricultural circular economy connotation and objectives, guided by the "3R" principles, and considering social, economic, and ecological benefits throughout agricultural production processes, we screened numerous factors through expert consultation and process understanding to select 20 evaluation factors for a comprehensive agricultural circular economy evaluation indicator system, using the entropy method to objectively determine weights for classification and individual indicators .

The indicator system comprises five dimensions: (1) **Input stage**: Total agricultural machinery power, agricultural labor force, crop sown area, fertilizer use intensity, and biogas digester count, where the first four reflect material inputs in agricultural production and the last reflects regional circular economy awareness and investment; (2) **Utilization stage**: Fertilizer effective utilization coefficient reflects resource utilization efficiency, while multiple cropping index, waste resource utilization level, and straw comprehensive utilization rate reflect resource recycling and further resource conversion levels; (3) **Output stage**: Agricultural GDP per unit area, per capita net income of farmers, commodity rate of agriculture-forestry-animal husbandry-fishery, and cultivated land output rate reflect socio-economic benefits achieved in agricultural production; (4) **Consumption stage**: Per capita vegetable consumption of farmers, farmers' green travel expenditure, and farmers' household housing area reflect agriculture' s impact on farmers' living standards and their circular economy practices. Farmers' household housing area is compared with the provincial average, with larger farmer housing area considered luxury consumption and thus a negative indicator; (5) **Effect stage**: Forest coverage rate, effective irrigation coefficient, comprehensive soil erosion control coefficient, and per capita arable land reflect agriculture' s impact on ecological environment and resource security. Input and utilization indicators primarily embody the "3R" principles, output and effect indicators evaluate socio-economic and ecological benefits, while consumption indicators reflect farmers' utilization of circular economy and its impact on their lives—the ultimate goal of agricultural circular economy development.

1.3 Agricultural Circular Economy Development Level Evaluation Method and Data Processing

The entropy method determines entropy values based on the variation degree of evaluation indicator values, which reflects the information quantity. A smaller entropy value indicates greater indicator variation and thus greater weight, while smaller variation leads to larger entropy and smaller weight. The comprehensive evaluation steps using entropy method are:

(1) **Determine evaluation objects, select indicators, and establish evaluation matrix**: Assuming evaluation of m samples in a province with n indicators, the jth indicator of the ith sample is denoted as Xij. Construct original data matrix $X = \{Xij\}m \times n$, where Xij represents the jth indicator value of the ith sample. In this study, $m = 16$ and $n = 20$.

(2) **Standardize original data**: This study uses the range method for indicator standardization. For positive indicators:

$$P_{ijt} = \frac{X_{ijt} - X_{\min}}{X_{\max} - X_{\min}}$$

For negative indicators:

$$P_{ijt} = \frac{X_{\max} - X_{ijt}}{X_{\max} - X_{\min}}$$

where $Xijt$ is the actual observed value of an indicator; $Xmax$ and $Xmin$ are the maximum and minimum values of that indicator in the cross-section data; and $Pijt$ is the standardized evaluation value.

(3) **Calculate entropy and information utility values**: The entropy value of each indicator can be calculated as:

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{m} P_{ijt} \ln P_{ijt}$$

Let $K = 1/\ln m$, then 0 *ej* 1. According to entropy method principles, faster indicator data change provides greater information quantity and greater system utility, resulting in larger weight.

The information utility value of an indicator is denoted as *dij*. The utility value of individual indicator *Xij* under classification indicator i is:

$$d_{ij} = 1 - e_j$$

(4) **Determine evaluation indicator weights**: The weight of individual indicator j under classification indicator i is:

$$w_{ij} = \frac{d_{ij}}{\sum_{j=1}^{n} d_{ij}}$$

(5) **Calculate classification indicator evaluation scores**: Based on calculated weights, the evaluation value is:

$$S_{it} = \sum_{j=1}^{r} w_{ij} P_{ijt}$$

where *Sit* is the comprehensive evaluation index of classification indicator i in year t (i = 1, 2, 3, 4, 5 represent input, utilization, output, consumption, and effect indices respectively), and r is the number of indicators in each subsystem.

(6) **Calculate classification indicator weights**: For multi-layer evaluation systems, the additivity of entropy can be used to determine upper-level weights *wj* proportionally from lower-level information utility values. After calculating each indicator' s utility value *dij* in previous steps, sum the utility values for each classification indicator to obtain *Di* (i = 1, 2, ···). The total utility value is:

$$D = \sum_{i=1}^{5} D_i$$

The corresponding classification indicator weight is:

$$w_i = \frac{D_i}{D}$$

(7) **Calculate agricultural circular economy development evaluation score**:

$$S_t = \sum_{i=1}^{5} w_i S_{it}$$

where *St* is the total evaluation value in year *t*, ranging from 0 to 1, with larger *St* indicating higher agricultural circular economy development level.

1.4 Agricultural Circular Economy Development Obstacle Factor Diagnosis Method

We employed three metrics– "Factor Contribution Degree," "Index Deviation Degree," and "Obstacle Degree" –to diagnose main obstacles. Factor contribution degree (*Fij*) represents a single factor' s impact on the overall objective (its weight). Index deviation degree (*Iijt*) represents the gap between individual indicators and agricultural circular economy development targets, calculated as the difference between the standardized indicator value and 100%. Obstacle degree (*Oijt*) represents the impact value of individual indicators on development level, which is the ultimate diagnostic result. Specific formulas are:

$$F_{ij} = w_i \times w_{ij}$$

where *wi* is the weight of classification indicator *i*, and *wij* is the weight of individual indicator *j* under classification indicator *i*.

$$I_{ijt} = 1 - P_{ijt}$$

where *Pijt* is the standardized indicator value calculated through extreme value standardization.

$$O_{ijt} = \frac{F_{ij} \times I_{ijt}}{\sum_{j=1}^{n} (F_{ij} \times I_{ijt})} \times 100\%$$

where *Oijt* is the obstacle degree of individual indicator *j* under classification indicator *i* in year *t*.

$$U_{it} = \sum_{j=1}^{n} O_{ijt}$$

where *Uit* is the obstacle degree of classification indicator *i* in year *t*.

2.1 Data Sources

Data were obtained from the *Jiangxi Statistical Yearbook* and *China Rural Statistical Yearbook* (2001-2016). The waste resource utilization level indicator lacked direct sources in statistical yearbooks. We calculated rural biogas digester numbers based on rural biogas production data from the *China Rural Statistical Yearbook*, assuming one 10 m^3 biogas digester produces 400 m^3 of biogas annually.

2.2.1 Classification Development Level Evaluation

Based on formulas (1)-(6), we calculated evaluation scores for each classification indicator and plotted the trends [Figure 3: see original paper]. From 2000 to 2016, the utilization, output, consumption, and effect indices of Jiangxi' s agricultural circular economy all showed upward trends. The output index increased most rapidly with a stable upward trend, reflecting rapid economic and social development. The effect index ranked second in growth magnitude, rising with fluctuations but remaining above 2000 levels, indicating continuous improvement in resource and environmental security. The consumption index ranked third, showing overall stable upward trends and reflecting improving rural living quality. The utilization index showed the smallest increase, rising initially then declining significantly before rising again, reaching its lowest point in 2008 —possibly due to snow disasters and low land use efficiency. The input index showed a downward trend, remaining below 2000 levels, reflecting insufficient attention to resource reduction input, which constitutes a major constraint on Jiangxi' s agricultural circular economy development.

2.2.2 Comprehensive Development Level Evaluation

Based on formulas (1)-(7), we calculated comprehensive evaluation values for Jiangxi's agricultural circular economy from 2000 to 2015 and plotted the trends [Figure 4: see original paper]. The results show that Jiangxi' s agricultural circular economy generally grew from 2000 to 2015, with an average annual growth rate of 3.43%—relatively slow growth—but with distinct 阶段性特征. The development can be divided into two phases: Phase 1 (2000-2008) showed minimal change, with 2008 development levels similar to 2000; Phase 2 (2008-2015) was a continuous growth period with an average annual growth rate of 8.05%, showing medium-high speed growth.

2.3.1 Individual Indicator Obstacle Factor Evaluation

Based on formulas (10)-(12), we calculated obstacle degrees for individual indicators in Jiangxi from 2000 to 2015, ranking indicators with obstacle degrees exceeding 5% . Obstacle factors changed over time. By occurrence frequency, two phases emerged: Phase 1 (2000-2008) most frequently featured agricultural labor force (C2), fertilizer use intensity (C4), fertilizer effective utilization coefficient (C6), straw comprehensive utilization rate (C9), agricultural GDP per unit area (C10), per capita net income of farmers (C11), cultivated land output rate (C13), farmers' green travel expenditure (C15), forest coverage rate (C17), and per capita arable land (C20). Phase 2 most frequently featured crop sown area (C3), fertilizer use intensity (C4), multiple cropping index (C7), and effective irrigation coefficient (C18). By obstacle degree magnitude, Phase 1 (2000-2008) main obstacles were fertilizer effective utilization coefficient (C6), fertilizer use intensity (C4), per capita arable land (C20), forest coverage rate (C17), and per capita net income of farmers (C11). Phase 2 (2009-2015) main obstacles were fertilizer use intensity (C4), multiple cropping index (C7), effective irrigation coefficient (C18), and crop sown area (C3). Fertilizer use intensity remained a primary obstacle throughout 2000-2015. Fertilizer effective utilization coefficient (C6), per capita arable land (C20), forest coverage rate (C17), and per capita net income of farmers (C11) ceased to be major obstacles after 2008, while multiple cropping index (C7), effective irrigation coefficient (C18), and crop sown area (C3) became major obstacles after 2009. Phase 1 featured many obstacle factors with relatively low degrees, while Phase 2 had fewer but more severe obstacle factors.

2.3.2 Classification Indicator Obstacle Factor Evaluation

To further diagnose the concentration and trends of obstacle factors from 2000 to 2015, we calculated classification indicator obstacle degrees based on formula (13), ranking those exceeding 20% . During 2000-2008, 3-4 classification indicators typically exceeded 20% obstacle degree with relatively low values, while during 2009-2015, typically only 2 indicators exceeded this threshold with higher values. Input indicators (B1) and utilization indicators (B2) were generally primary obstacles throughout 2000-2015, with their obstacle degrees gradually increasing. Output indicators (B3) and effect indicators (B5) were also major obstacles during 2000-2006 but ceased to be primary factors after 2007.

3 Conclusions and Discussion

This study constructed an evaluation system comprising input, utilization, output, consumption, and effect indicators based on circular agricultural production processes, used the entropy method to determine indicator weights, and calculated comprehensive and stage-specific development evaluation values for Jiangxi' s agricultural circular economy from 2000 to 2015. We diagnosed main obstacle factors using "Factor Contribution Degree," "Index Deviation Degree," and "Obstacle Degree." Main conclusions are:

(1) From 2000 to 2016, the utilization, output, consumption, and effect indices of Jiangxi' s agricultural circular economy all showed upward trends, with growth magnitudes ranking as output > effect > consumption > utilization, while the input index showed a downward trend.

(2) Jiangxi' s agricultural circular economy growth from 2000 to 2015 showed an overall upward trend with an average annual growth rate of 3.43%,

indicating relatively slow growth.

(3) Main obstacle factors during 2000–2008 were fertilizer effective utilization coefficient, fertilizer use intensity, per capita arable land, forest coverage rate, and per capita net income of farmers; during 2009–2015 they were fertilizer use intensity, multiple cropping index, effective irrigation coefficient, and crop sown area.

(4) Input and utilization indicators were the primary obstacles affecting Jiangxi' s agricultural circular economy development from 2000 to 2015, with their obstacle degrees gradually increasing, while obstacle degrees of output, consumption, and effect indicators generally decreased. Specifically, input indicator obstacle degree increased from 17.50% in 2000 to 50.00% in 2015; utilization indicators from 24.34% to 32.94%; output indicators decreased from 25.23% to 0.00%; consumption indicators from 9.92% to 4.19%; and effect indicators from 23.01% to 12.87%.

This study evaluated Jiangxi' s agricultural circular economy development and diagnosed main obstacles from the IUPCE perspective, achieving certain research results but with limitations: First, indicator selection limitations. Most input, utilization, output, and effect indicators were selected based on existing research, while consumption indicators were selected based on operability principles, circular agriculture connotation, and expert opinions, including per capita vegetable consumption, green travel expenditure, and housing area. Farmers' green travel expenditure data were obtained through a 2016 summer questionnaire survey of 1,000 households in 20 villages around Nanchang, finding 99.9% of rural residents used low-carbon transportation (electric vehicles, buses) with negligible private car use. Considering lower economic development before 2016 led to more low-carbon travel, we combined this with statistical yearbook transportation fees to estimate the indicator, which may contain some bias. Second, this study only conducted provincial-level analysis without examining spatial variations across cities and counties. Comprehensive data collection and comparative spatial analysis across cities and counties represents a future research direction.

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Note: Figure translations are in progress. See original paper for figures.