

Research on optimization of food system based on multi-objective programming

Junda Li¹, Fuyou Mao^{2,*}

¹ College of Management, Shenyang Jianzhu University, Shenyang, China, 110168

² College of Computer Science and Technology, Shenyang Jianzhu University, Shenyang, China, 110168

* Corresponding Author Email: mfy15541207057@gmail.com

Abstract. Using Principal Component Analysis (PCA), 9 indicators with large influence degree were selected, which consist of the basis for two-level fuzzy comprehensive evaluation model and multi-objective optimization model. Model one is to establish a secondary fuzzy comprehensive evaluation model. Model two is to build a multi-objective Food System Optimization Model. Results show that the optimization of sustainability in the United States made the food system more stable, and the optimization of fairness in Brazil was more conducive to the improvement of the food system.

Keywords: PCA, multi-objective, optimization, sustainability, stable.

1. Introduction

Food security is always the most important issue for the survival of mankind. However, “Food system”, which is the whole chain to meet food demand of people, is nowadays in jeopardy for many regions around the world. Influenced by SARS-CoV-2 in 2019, the global hunger level has been rising significantly, and food security is also undergoing a great instability. Not only people in poor and marginalized regions, but also people in rich regions suffers from food insecurity. To optimize and improve the food system are great challenges for solving the sustainable problems of the food system. Factors affecting food security cover the whole process of the food system, and can be classified into four aspects — efficiency, benefit, fairness and sustainability. Using Principal Component Analysis (PCA) to obtain the comprehensive indicator playing the leading role, build a food system evaluation model to obtain comprehensive evaluation scores.

2. Evaluation model

2.1. Fuzzy Synthetic Evaluation Model

2.1.1 Data normalization

Using PCA, the number of the indicators is reduced effectively and 9 indexes are finally obtained as our primary indicators.

Comparing these 9 indicators, the indicators can be classified into two types, cost-type Indicator and benefit-type Indicator.

For cost-type Indicator:

$$x_{ij} = \frac{x_i^{max} - x_{ij}}{x_i^{max} - x_i^{min}}, i = 1, 2, \dots, 9; j = 1, 2 \quad (1)$$

For benefit-type Indicator:

$$x_{ij} = \frac{x_{ij} - x_i^{min}}{x_i^{max} - x_i^{min}}, i = 1, 2, \dots, 9; j = 1, 2 \quad (2)$$

Table 1. Framework of The Primary Indicators

Indicators	Varname	Explanation
Food production and processing	x_1	It refers to the production and processing process
Mechanization degree	x_2	The proportion of the completed quantities of mechanized construction in the total quantities
Proportion of agricultural land	x_3	It denotes the actual control of the land area
Grain circulation cost	x_4	It represents the cost in the process of grain circulation
Dosage of chemicals	x_5	It shows the chemicals used in the production
Crop diversity	x_6	It shows the variety of crops per unit area
Irrigation resources	x_7	It refers to the utilization rate and amount of fresh water
Greenhouse gas emissions	x_8	It represents the product of crop combustion and decomposition.
Food distribution	x_9	It represents the amount of food per capita

2.1.2 Quantification of qualitative indicators

Fuzzy evaluation is adopted to solve this problem. In this model, we let U denote evaluation set; and A is weight set, obtained by EWM (XX); W is a set of comments made up of grade such as Level A, Level B, Level C and Level D. The relationship between W and U is described by fuzzy evaluation matrix T . The comprehensive evaluation model P is given by

$$P = AT = (p_1, p_2, p_3, \dots, p_n) \tag{3}$$

F denotes the set of score, so the evaluation score Z is calculated ultimately using the following formula:

$$Z = PF \tag{4}$$

2.1.3 Weighting Models of Evaluation Indicators

Weighting models is quite essential because it determines the contribution of each indicator to target value. In order to avoid the influence of subjective factors, the entropy weight method is adopted.

First, standardize the initial data:

$$P_{IJ} = \frac{Y_{ij}}{\sum_{i=1}^n Y_{ij}} \tag{5}$$

Second, calculate the information entropy based on the standardized data from equation (11):

$$E_j = \ln(n)^{-1} \sum_{i=1}^n p_{ij} \ln p_{ij} \tag{6}$$

Third, the weight for each factor was calculated as:

$$W_i = \frac{1-E_i}{9-\sum E_i}, (i = 1,2,\dots,9) \tag{7}$$

Finally, the weights of 9 indicators were obtained.

Table 2. Weights Pf 9 Indicators

x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
0.01	0.14	0.25	0.08	0.10	0.24	0.09	0.01	0.07

2.1.4 Comprehensive Evaluation Indicator

2.1.4.1 Determination of second-class indicator

The second-class indicator include The Efficiency (EF), Profitability (P), Sustainability (S) and Equality (EQ), which are determined by weights and values of primary indicators. These four indicators aims at evaluating the four dimensions of the food system.

◆ Efficiency (EF) consists of food production and processing and mechanization degree. It reflects the resources and ecological carrying capacity and local science and technology level.

◆ Profitability(P) consists of proportion of agricultural land and grain circulation cost. It is used to evaluate the profitability of the current food system.

◆ Sustainability(S) includes dosage of chemicals, bio-diversity, irrigation resources and greenhouse gas emissions. It reflects the sustainable development ability of food system.

◆ Equality (EQ) is represented by food distribution. It is used to measure whether the food system can meet the normal living needs of local residents.

The composition of the criterion layer and the weights were shown in following Table.

Table 3. The Weights Of Second-Class Indicators

Second-class indicators	Primary indicators and weights	Second-class indicators	Primary indicators and weights
Efficiency(EF) (28.7%)	Food production and processing(35%)	Sustainability (S)(17.2%)	Dosage of chemicals(23%)
	Mechanization degree(65%)		Crop diversity(17%)
Profitability (P)(39.6%)	Proportion of agricultural land(42%)		Irrigation resources(41%)
	Grain circulation cost(58%)		Greenhouse gas emissions (19%)
		Equality (EQ)(14.5%)	Food distribution

2.4.1.2 Determination of first-class indicator

Based on weights and values of second-class indicators, a comprehensive indicator is finally obtained to evaluate the integral security level of food system for a region. The comprehensive Indicator equals to the weighted sum of second-class indicators:

$$A = w_1 \times EF + w_2 \times P + w_3 \times S + w_4 \times EQ \quad (8)$$

where w_i is the weight of i th second-classindicator. The specific weights were as follows:

$$w = [0.1420, 0.4265, 0.1135, 0.0480] \quad (9)$$

The scale measurement value is established to obtain the weighted evaluation model, which is the final evaluation function of the grain system.

$$A = 4b_1 + 3b_2 + 2b_3 + b_4 \quad (10)$$

Finally, the score of current grain system is obtained:

$$A = 4 \times 0.1420 + 3 \times 0.4625 + 2 \times 0.1135 + 0.480 = 3.2025 \quad (11)$$

In this regard, we will establish an optimization model for fairness and sustainability on the basis that the efficiency and benefit ability reach the standard.

2.2. Multi-objective Food System Optimization Model

The optimal allocation of grain system follows three steps: the establishment of objective function, the setting of constraints and the adjustment of model parameters.

2.2.1 Construction of objective function

In this optimization model, we focus on five factors: food distribution, the use of chemical agents, crop diversity, irrigation resources and greenhouse gas emissions.

Therefore, when establishing the model, more attention should be paid to solve the planning variables for each region, rather than regard the country as a whole.

The objective function of the multi-objective grain system optimization model is as follows.

$$F(Y) = \{f_1(Y), f_2(Y)\} = \begin{cases} f_1(Y) = \sqrt{\frac{1}{N} \sum_{i=1}^N (N_i - \mu)^2} \\ f_2(Y) = \sum_{i=1}^4 q_i |p_i - y_i| \end{cases} \quad (12)$$

$Y = \{y_1, y_2, y_3, y_4, y_5\}$ is the decision variable solution set of five objective functions, which is the digital expression of the regulation of five influencing factors. The two objectives of the optimization model are fairness optimization and sustainability optimization.

- Objective function of fairness

The fairness of a country's food system is difficult to measure quantitatively and abstractly. This paper uses PCA to determine that when measuring the health standard of the national food system, the distribution of food reflects the fairness of the food system indirectly to a great extent.

- Objective function of sustainability

In the principal component analysis, there are four main factors that affect the sustainability goal. This paper uses reverse thinking to consider the harmful effects of the four factors on grain production, and digitally superimposes the harmful effects of the four factors.

2.2.2 Setting of constraint condition

- ◆ Food distribution

The constraint of food distribution is the amount of food for each person. This model assumes that one person can be given the amount of food demand for up to two people, and special circumstances are not taken into account.

$$y_1 \leq 2Q_1 \quad (13)$$

y_1 Represents the total amount of food allocated to each person in a year and Q_1 represents the food demand of an adult in one year.

- ◆ Dosage of chemicals

Excessive use of chemicals not only affects soil quality, but also has side effects on the production of agricultural products. In this optimization model, the sustainability of land is mainly considered, so it is necessary to reduce the use of chemicals as much as possible without exceeding the capacity of land to support drugs.

$$\min(y_2) \leq Q_2 \quad (14)$$

y_2 represents the amount of agricultural chemicals used in a certain area and Q_2 indicates the maximum dosage of pesticide used in the land.

- ◆ Crop diversity

The restriction of crop diversity is a very abstract condition. In the farmland system, too many or too few crop species will affect the balance of the system, so this model limits the number of species and crop decision criteria to the ecological feasible range.

$$Q_{3min} \leq y_3 \leq Q_{3max} \quad (15)$$

y_3 represents the number of species in an area, Q_{3min} and Q_{3max} represents the minimum and maximum of the number of crop species in the region based on the ecological perspective.

◆ Irrigation resources

In agricultural production system, irrigation resources generally refer to the utilization rate and the amount of fresh water.

$$\begin{aligned} y_4 &= Q_4 - R \\ \mu &= \frac{y_4 - \Phi}{y_4} \geq 0.6 \end{aligned} \quad (16)$$

y_4 represents the amount of irrigation resources used in the area over a period of time, Q_4 represents the fresh water demand of the region over a period of time, R represents the total rainfall in this period, Φ represents the amount of fresh water remaining and η represents the utilization rate of irrigation resources.

◆ Greenhouse gas emissions

The gas emission of agricultural system is mainly the product of crop combustion and decomposition by decomposers. The gases produced include carbon dioxide, carbon monoxide and so on. The model limits the total amount of various gases.

$$\sum_{i=1}^n \sum_{j=a}^m T_i K_j \leq N \quad (17)$$

T_i and K_j respectively indicate the type of gas and the emission of each path of a gas over a period of time. N regards the largest emission of greenhouse gases in the country.

◆ The decline of efficiency and benefit

The goal of this problem is also to solve the problem of national food shortage.

When optimizing the system, we should also consider the minimum standard of national food, otherwise excessive consideration of the fairness and sustainability of the system will affect the national economic development and the essence of the grain problem.

$$\begin{aligned} \Delta \text{benefits} &= \frac{1}{\alpha} \Delta y_1 \leq w_1 \\ \Delta \text{efficiency} &= \sum_{i=2}^5 \frac{1}{\beta_i} \Delta y_i \leq w_2 \end{aligned} \quad (18)$$

$\Delta \text{benefits}$ and $\Delta \text{efficiency}$ represents the decline of efficiency and benefit respectively, α represents the reference coefficient of the relationship between grain distribution and benefit change, β_2 and β_5 represent the reference coefficient of the relationship between the four factors affecting sustainability and efficiency, w_1 and w_2 represent the maximum capacity of a country to accept changes in efficiency and efficiency.

2.2.3 Adjustment of model parameters

2.2.3.1 Model application

We apply the model to the United States and Brazil, respectively. For the United States, as the largest food exporter, food production has always been in a high position, and its profitability is higher than other developed countries.

Similarly, Brazil, as a developing country, has the fourth largest crude grain production in the world, and corn production has been among the highest in the world all year round.

According to the above objective function and condition function, the developed country America and developing country Brazil were solved respectively.

To sum up, through the model optimization of fairness and sustainability, we can know that optimizing fairness and sustainability is more conducive to the stability of food system under the premise of considering efficiency and benefit.

● Benefits

For the United States, the food system is highly optimized for sustainability on the premise of good efficiency. For Brazil, the grain distribution has been optimized to a greater extent, which is reflected in the weakening of the proportion of grain waste, the change of the defects of the previous imperfect fairness, and the enhancement of fairness on the basis of efficiency is more conducive to the improvement of the food system.

● Cost

Under the background of global warming, greenhouse gas emissions will increase the area of desertification and the proportion of agricultural land will become smaller and smaller, which will inevitably have an unpredictable impact on the food system. Not only does it lead to the destruction of the food system, but the erosion of efficiency and profitability is increased, and more serious is the threat to the ecosystem. Therefore, we anticipate that in the future, as climate conditions change, all mankind will pay more attention to prioritizing the impact of sustainability.

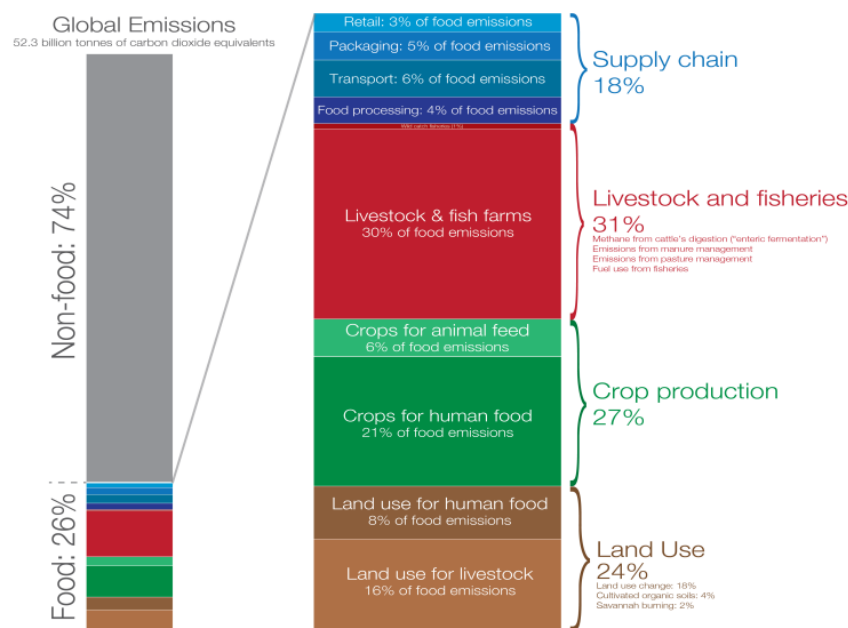


Fig 1. Share of CO2 emission

3. Model Evaluation And Improvements

3.1. Strengths

- The core of our model is to optimize the current model by changing the focus of the grain system.
- The model is compatible and flexible in the analysis of food system for developed and developing countries.
- The model combines the large sample data covers the relevant knowledge of environmental science and nutrition policy science, which helps evaluate the existing problems of the model scientifically.

3.2. Weaknesses

- The framework of the model is large and the relationships of sub-models are not that close, making the model not conducive for linkage analysis.
- Although within each biome there are differences which would affect the ecological impact of a land-use project, we do not take these into account.

3.3. Improvements

- The food system model for specific countries can be more accurate if more complete data can be obtained;
- The integrated use of multiple evaluation models can bridge the gap between the supply value of grain producers and the demand value of consumers, and reduce the impact on the stability of the model.

4. Conclusion

Given the different development conditions, the ultimate goal of optimizing and improving the food system is to combine efficiency, efficiency, sustainability and fairness. We also point out in our report that there have been significant changes in the food system. In developed countries such as the United States, the long-term security and stability of the food system requires a strong incentive to have a healthier diet that combines the benefits of food systems with sustainability. In developing countries such as Brazil, changes in food distribution are required to reduce the loss of processing and production in the food system and to continuously optimize the impact of equity in the food system. Of course, different countries and regions should make different adjustments based on local conditions. In a word, food security and sustainable development are important issues of economic and social development, and also the most basic goals of global human struggle. The continuous optimization and improvement of food system are the best expectation of each of us.

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