Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
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Who moved my food? A new food system optimization

Summary

Hunger breeds discontent. As the population continues to increase, food scarcity becomes more and more serious. Thus, we established a new, effective and flexible food system, and used the planning model to optimize the system and give the solution.

Firstly, we build a new food system based on **food economics**. Among them, there are 4 first grade indexes, efficiency, profitability, equity and sustainability, and 12 second grade indexes. We used Analytic Hierarchy Process (AHP) to determine the weight of the index and obtain the coefficient of the object function. Taking China as an example, we only set up a **linear programming model** to optimize the equity and sustainability, get the optimized solution, and compare it with the original system. In estimating the time to reach this level, we obtain the function expression of the index change through regression. The results show that this time is around 4-6 years.

Secondly, we establish a **target planning model** and use priority factors to express the priority, and then to realize a food system that can adjust the priority flexibly. Here, we introduce the concept of **C**omprehensive **O**ptimized **I**ndex (**COI**) to select which priority food system is optimized. We take China and the United States as examples. The results show that China's priority is **efficiency>equity>profitability>sustainability**, and its COI value is 13.75. The United States' priority is **efficiency>profitability>equity>sustainability**, and its COI value is 9.78.

Then, we get that China's food system reaches this level, and it will take 2-4 years. In the case of **Pareto optimized**, we introduce the concept of **A**gricultural **I**nvestment **E**ffectiveness **C**oefficient (**$AIEC$**) from agricultural economic management to evaluate the benefits and costs of the food systems in China and the United States. The results show that the $AIEC$ values of China and the United States are 0.83 and 0.46.

Finally, we conducted a sensitivity analysis of the model, adjusted the parameters of the constraint conditions with a fixed step length, evaluated the optimization effect, and then applied the model to a smaller area for solution. The advantages and disadvantages of the model are also analyzed.

Keywords: Linear programming; Priority Factors; Target planning model; Pareto optimum

Contents

1 Introduction

1.1 Problem Background

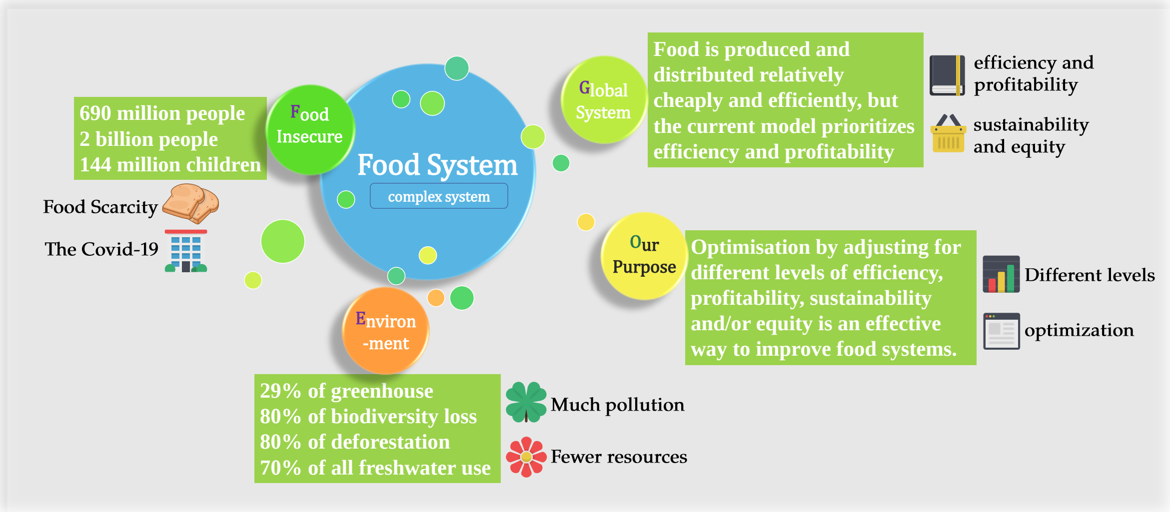

Figure 1. Problems with the food system and our purpose

As one of the most important survival resources of human beings, food forms a complex system all over the world. As we can see, however, that our global food system is unstable even in the parts of the world that it generally serves well. At present, there are still problems in the world, such as food scarcity, food security, environmental sustainable development and equity.

As of 2019, 690 million people around the world suffer from hunger, 2 billion people do not have regular access to safe, nutritious and adequate food, and 144 million children are stunted. Since 2020, the Covid-19 pandemic has had a severe impact on the global food system, severely affecting vulnerable populations and significantly increasing the number of hungry people compared to before [1]. Even in developed countries with abundant material resources, there are still food starved areas and citizens who do not have access to normal food and nutrition.

Additionally, environmental sustainability is also an issue that we must pay attention to. The process of developing the global food system has resulted in "29% of greenhouse gas emissions, ... up to 80% of biodiversity loss, 80% of deforestation, and 70% of all freshwater use". Experts underscore that options for sustainable food systems include sustainable intensification, less resource-intensive diets, improving feed efficiency, reduction of food losses, reducing food waste, recycling of nutrients and reducing the use of biofuels and natural fibers. This is a frightening phenomenon. If we don't develop the food system on the basis of sustainability, we will gradually lose the future of the food system.

The food system, made up of huge national and international food producers and distributors, makes food relatively cheap and efficient to produce and distribute, but it is fraught with problems. This current model prioritizes efficiency and profitability, resulting in countries' food policies often being adjusted to changes in food supply and demand, while equity and sustainability are often deferred. Therefore, optimizing by adjusting for various levels of efficiency, profitability, sustainability and/or equity is an effective way to improve food systems.

1.2 Our Work

First, based on food economics, we establish a new food index system with efficiency, profitability, equity and sustainability as the first grade index, using Delphi method and Analytic Hierarchy Process (AHP) to determine the index weights to obtain a linear relationship.

Next, we take China as an example, only for equity and sustainability, establish a linear programming model to optimize the food system. We use the maximum value of the weighted sum of each factor as the objective function, through MATLAB programming, to achieve the model solution, and compare with the original system. Finally, the function expression of the index change is obtained through regression, and the time to realize the optimization is further obtained.

Secondly, on the basis of partial optimization of the system only for equity and sustainability, we use the goal planning model to express the priority with a priority factor, establish a food system model that can flexibly adjust the priority of the goal, and borrow the first question. Method to find the time to reach the optimized level. Next, we introduce the concept of Comprehensive Optimized Index (COI) to evaluate the effect of the food system. The higher the value of COI, the more food systems equipped with corresponding priorities should be adopted. We take China and the United States as examples to solve the model, hoping to get the priority ranking and COI results.

The Pareto optimized situation can guarantee the equity of food production and exchange to a great extent. We introduced the concept of Agricultural Investment Effectiveness Coefficient ($AIEC$) from agricultural economics and management to evaluate the benefits and costs of the food systems in China and the United States and compare them.

Finally, according to the target planning model with priority factors, we conduct sensitivity analysis under different scales of food systems, including scalability analysis and adaptability analysis. In the analysis, the parameters of the constraint conditions are adjusted with a fixed step length to evaluate the optimization effect, and then the model is applied to a smaller area to solve. After that, we analyzed the advantages and disadvantages of the model.

1.3 Notation

Table 1. Symbol description and explanation

Symbol	Definition
x_{ij}	Secondary index values of the food system
ω_{ij}	Index weight
$T_{min-China}$	Minimum time to reach a certain level
$T_{max-China}$	Maximum time to reach a certain level
P_i	Priority factor of objective programming model
COI	Comprehensive Optimized Index
$AIEC$	Agricultural investment effect coefficient

2 Assumptions and Glossary

2.1 Assumptions

- **We ignore the influence of the drastic change of the index value on the optimization effect.** We think that in a certain period of time, the change of the index value in the food system is in line with the development law of economics and environmental science.
- **We assume that the error caused by parameter estimation has a controllable influence on the optimization effect.** Since the data of some indexes cannot be obtained, we usually choose other indexes to estimate the indexes with missing data. This process may produce errors.
- **The total amount of natural renewable water is not included in the calculation of the total amount of renewable water in this paper.** The total amount of renewable water actually includes the total amount of underground renewable water (actual) and the total amount of natural renewable water, but the latter cannot be estimated.

2.2 Glossary

- **Effect coefficient of agricultural investment:** Refers to the increase of agricultural output value or value added per unit agricultural investment. It reflects the economic benefits of funds used by the whole society to expand agricultural reproduction. It's calculated by the formula: Effect coefficient of agricultural investment Increase in total agricultural output (or value added) over the same period- Investment in agriculture over a time period.
- **Agricultural greenhouse gas emissions ($AGGA$):** The amount of greenhouse gases

released into the atmosphere during agricultural cultivation and production mainly includes CO_2, CH_4, N_2O and so on. Agriculture is not only an important source of CO_2 emissions, but also the root cause of global warming, it is also the most vulnerable industry to climate change.

- **Renewable water consumption for agricultural use ($RWCAU$):** Reclaimed water is the effluent of sewage after advanced treatment, it is one of the important unconventional water sources in the city, the use of reclaimed water in agricultural irrigation can improve the yield and production efficiency of corresponding crops.
- **Total household demand for grain ($THDG$):** The total amount of food a household needs in a year, including grains, vegetable products, animal products and other foods. The index can reflect the efficiency of the food system and provide a basis for improving the food system.
- **Investment in grain production (IGP):** Investment in food production includes land, capital and labor factors. The increase of agricultural output can be decomposed into the contribution of the increase of the input of production factors and the contribution of the increase of factor productivity.

3 Reinventing the Food System: a New Attempt

For the current food system, we only consider the shortcomings of efficiency and profitability. We want to come up with a new food system, and it can be optimized to our ideal state. Additionally, we hope that the new system can be optimized by mathematical methods on the premise of satisfying the economic theory.

3.1 A New Food System

Based on food economics, we fully considered the relationship between supply and demand in the market, the relationship between food price and cost fluctuation [2]. Meanwhile, we have established a new food index system by referring to the "Food Security Measurement Indexes" in the book and the "Sustainable Food System Security Index" in the Harvard database as shown in **Figure 5** [3-5].

We select four first grade indexes (efficiency, profitability, equity and sustainability) and correspondently select twelve second grade indexes. Additionally, we do not select many unrelated indexes, which would remove obstacles for the subsequent model optimization and make a better mechanism analysis of the influence of each index.

3.2 Optimization Only for Equity and Sustainability

Then, we need to optimize the performance of the food system. In operations research, when we deal with programming problems, we usually list the objective function and constraint conditions according to the actual problems in most cases. Simultaneously, we want a linear relationship between the first grade indexes and the second grade indexes. Therefore, we determine the index weights by the Delphi method and the Analytic Hierarchy Process (AHP) and the results are shown in Table 2 and Table 3.

Thus, we can get the linear relationship between the first grade indexes and the second grade indexes. We define ω as the weight, therefore we have:

$$x_i = \sum_{j=1}^{n} \pm\omega_{ij}x_{ij} \tag{1}$$

Next, taking China for example, we select relevant data in 2016 from the data set and use linear programming method to solve the model [6]. If the food system is optimized only for equity and sustainability, the mathematical model is:

$$max\ z_1 = -\sum_{j=1,j\neq 3}^{4} \omega_{1j}x_{1j} + \omega_{13}x_{13} + \sum_{j=1}^{3} \omega_{2j}x_{2j} \tag{2}$$

$$s.t.\ \begin{cases} 0.1x_{13} - x_{12} - x_{14} \geq 3000 \\ x_{22} - x_{21} \leq 0.1 \\ x_{11} \leq 700, x_{23} \leq 0.08 \\ x_{1j}, x_{2k} \geq 0, (j = 1, \cdots, 4; k = 1,2,3) \end{cases} \tag{3}$$

Table 2. The first grade indexes weight of food system

First grade indexes	Sustainability (x_1)	Equity (x_2)	Efficiency (x_3)	Profitability (x_4)
Weight	0.2715	0.2051	0.3002	0.2232

Table 3. The second grade indexes weight of food system

Second grade indexes	AGGE (x_{11})	RWCAU (x_{12})	TRW (x_{13})	ORWC (x_{14})
Weight	0.0571	0.0839	0.0927	0.0378
Second grade indexes	UPCL (x_{21})	RPCALA (x_{22})	PAEGE (x_{23})	TGP (x_{31})
Weight	0.0558	0.0579	0.0914	0.1638
Second grade indexes	THDG (x_{32})	CFP (x_{41})	PGP (x_{42})	IGP (x_{43})
Weight	0.1364	0.0723	0.0922	0.0587

Note: All the indexes in the table are abbreviations of Second grade indexes. Please refer to **Appendix A** for full names.

For the convenience of expression, we may consider z_1 as a comprehensive index, which is used to evaluate the equity and sustainability of the existing system. The larger the index value is, the more prominent the optimization effect in these two aspects will be.

We take the maximum value of the weighted sum of each index as the objective function, and the constraint condition is the optimized range of these indexes. For example, the limit of $x_{12} \leq 0.08$ means that the agricultural expenditure should not exceed 0.08 of the total fiscal revenue of the country (region), which is the consensus of experts and scholars at home and abroad [10-12]. $+\omega_{13}x_{13}$ appears because dex x_{13} plays a positive role in the food system. The larger the $+\omega_{13}x_{13}$ value is, the better the overall effect of the food system will be. Additionally, we realize model solving through MATLAB programming. The program is shown in **Appendix B**, and the optimized solution of the model is shown in Table 4.

Table 4. Optimized Solution of Linear Programming Model (China)

Optimized solution	x_{11}	x_{12}	x_{13}	x_{14}	x_{21}	x_{22}	x_{23}
Value	640.3	1468.1	71829	2308.1	0.05	0.09	0.06

Note: Due to space constraints, units are omitted here.

3.3 Characteristic Analysis of System Changes

After optimizing the equity and sustainability of the food system, we need to analyze what is the cost of this optimization. The original food system was established on the basis of full consideration of efficiency and profitability, which can be called an optimization result. For the convenience of expression, the original system is called **System A**, and the resulting system is called **System B**, which is optimized for equity and sustainability. Additionally, we hope that this relationship can be clearly reflected through the analysis of the internal relationship of each variable in Figure 2 and Figure 3.

After comparison, we find that the values of positive indexes in System B are all reduced compared with System A. Instead, the values of negative indexes (For example: the proportion of agricultural expenditure in government expenditure, PAEGE) are increased. The results show that the linear programming model has more strict requirements on the values of these two indexes in order to improve the equity and sustainability of the food system.

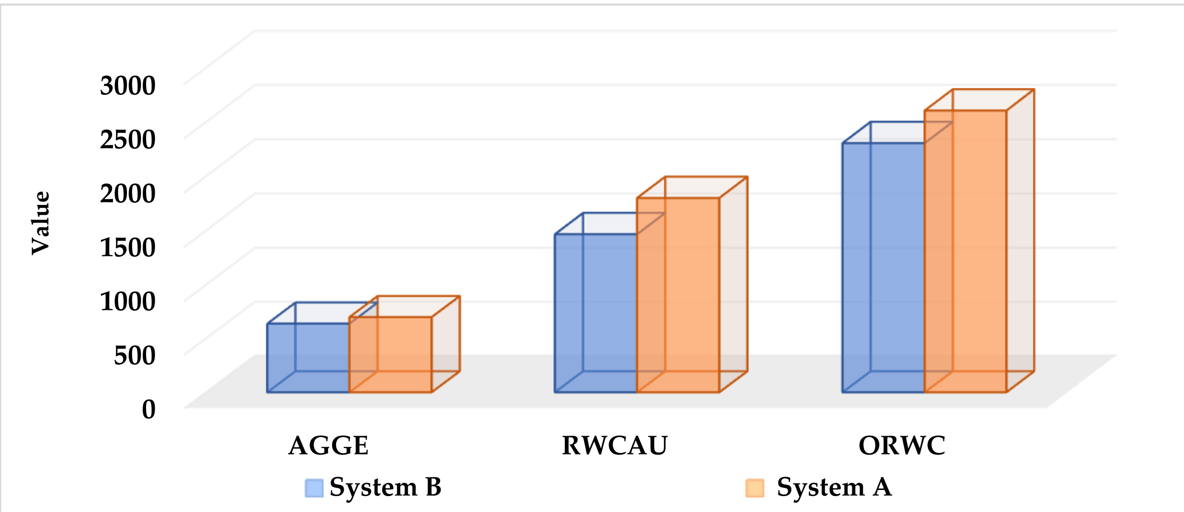

Figure 2. Numerical comparison of the sustainability indexes of the two systems

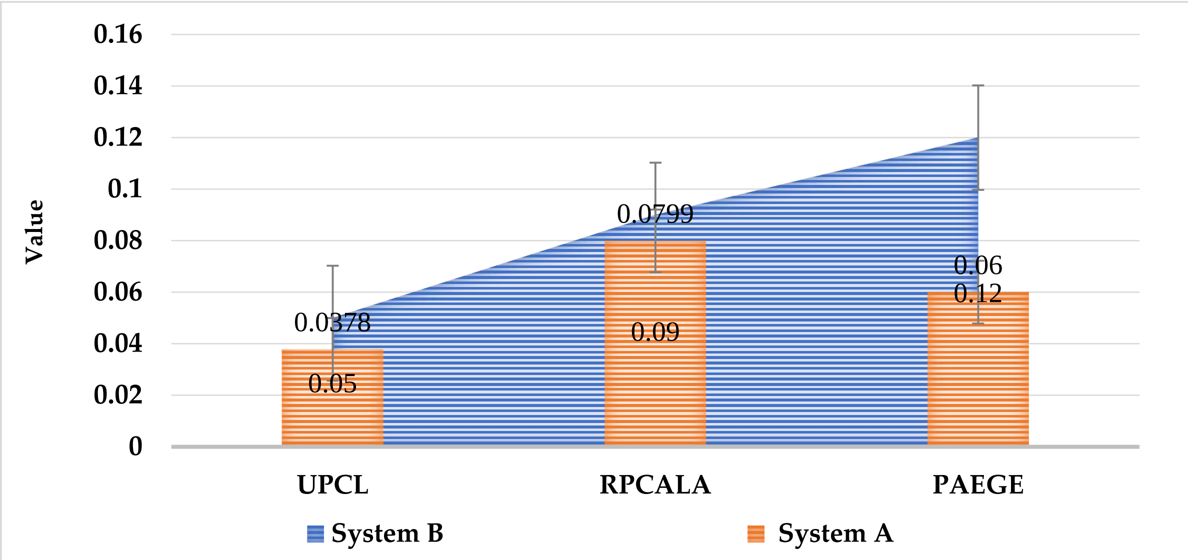

Figure 3. Comparison of equity index values between the two systems

3.4 Estimation of the Time to Achieve the Optimized Goal

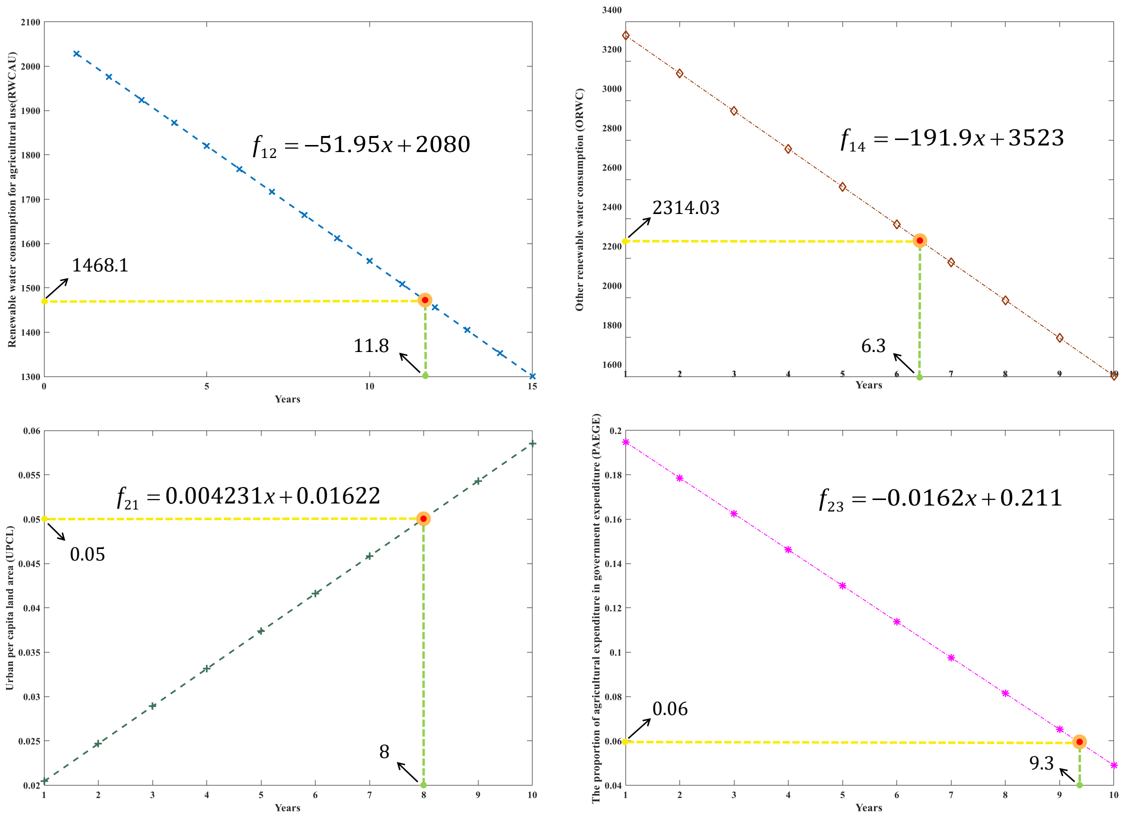

Figure 4. Fitting graphs of four predictable indexes (RWCAU, ORWC, UPCL and PAEGE)

After model optimization and characteristic analysis, we are more concerned about when a country will reach this level, but there are only rough estimates here. Therefore, we collected the index values of China from 2011 to 2015. As for the default values, we use KNN algorithm to fill [13-15]. After obtaining the complete data set, we carry out curve fitting by the cftool toolbox of MATLAB. For the convenience of estimation, we adopt linear fitting to obtain the trend of each index over time as shown in Figure 4.

In particular, we find that some index values are not close to the optimized value of System B, but gradually moving away from it, which can only be enforced at the national level. Therefore, we consistently measure such data over a period of 5 to 15 years.

$$T_{min-China} = \frac{6.8+1.3+3+10+5}{6} \approx 4.4\ (years) \tag{4}$$

$$T_{max-China} = \frac{6.8+1.3+3+10+15}{6} \approx 6.0\ (years) \tag{5}$$

Finally, we estimate that it will take at least 4 to 6 years for China to reach the index levels of System B through Equations (4) and (5).

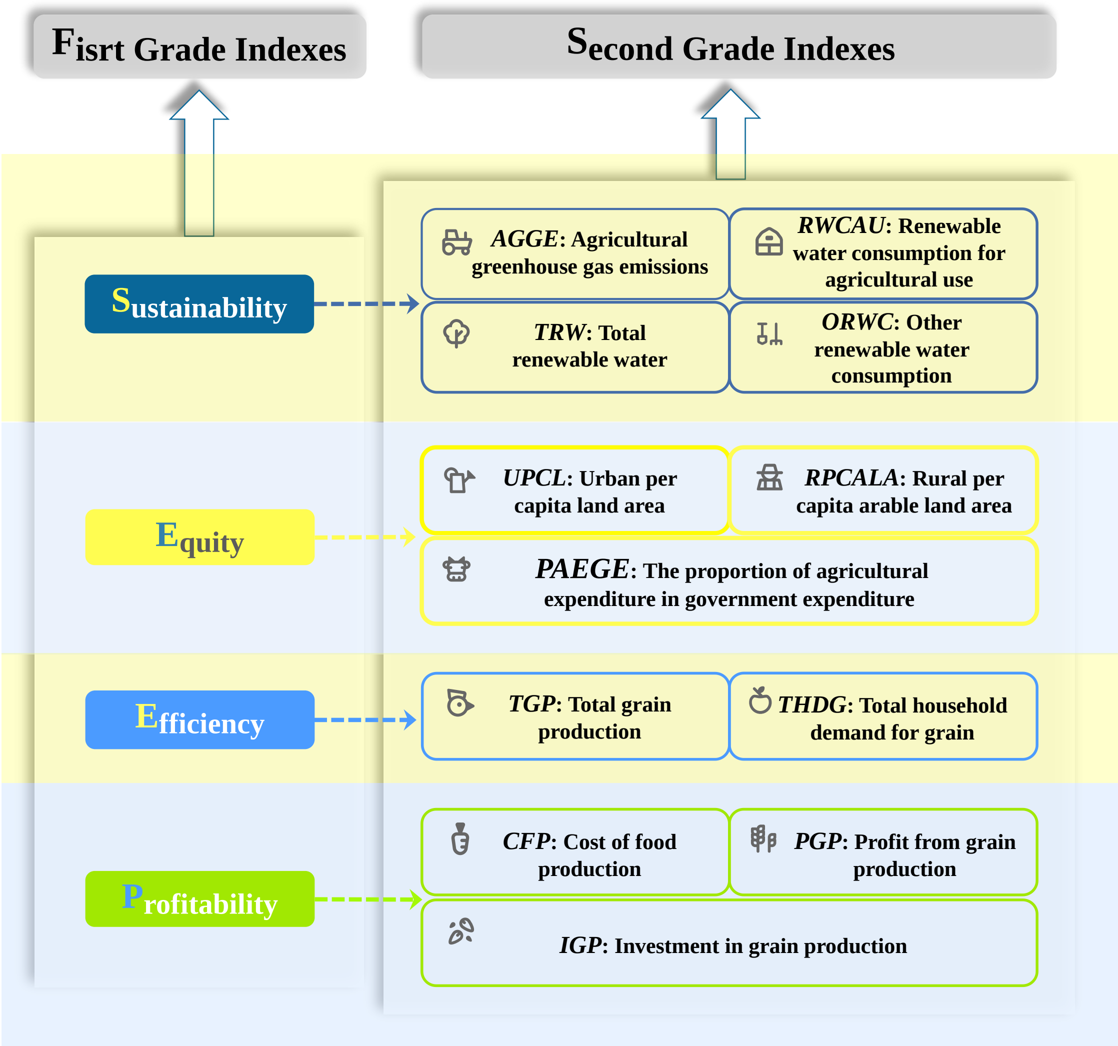

Figure 5. Concept map of the new food system

4 A Flexible Food System Model

In Chapter 3, we only partially optimized the food system for equity and sustainability. Moreover, using linear programming model for optimization can only solve the maximization or minimization of a single objective under rigid constraints. But in practical problems, we often need to consider multiple goals, some primary, some secondary. Therefore, we require to use the method of goal programming to build a food system model that can flexibly adjust the priority of goals.

4.1 A Food System Model: Changing the Priority of Goals

We still obtain inspiration from operations research and introduce the concept of priority factor P. Priority factor reflects the difference in the importance of goals When we do multiple goal planning. If there are n priority factors, it should satisfy the following formula:

$$P_1, P_2, \cdots, P_n \ (P_k \gg P_{k+1}, k = 1,2, \cdots n-1) \tag{6}$$

$P_k \gg P_{k+1}$ indicates that the priority of target P_k should be greater than P_{k+1}.

Taking China for example, we still use each values of indexes in 2016 [21]. At the same time, we add positive and negative deviation variables (d^+, d^-) to the objective programming model. The deviation variables are different from the rigid constraints of linear programming model, they are soft constraints [16]. If we hope the sequence from high to low is: sustainability, equity, efficiency, profitability, then the target programming model is:

$$min\ z = P_1 d_1^+ + P_2 d_2^- + P_3(2d_3^- + d_4^+ + d_4^-) \tag{7}$$

$$s.t. \quad \begin{cases} 0.1x_{13} - x_{12} - x_{14} + d_1^- - d_1^+ = 3000 \\ x_{22} - x_{21} + d_2^- - d_2^+ = 0.1 \\ 0.7x_{31} - x_{32} + d_3^- - d_3^+ = 0 \\ x_{41} + x_{42} - x_{43} + d_4^- - d_4^+ = 0.8 \\ x_{11} \le 700, x_{23} \le 0.08 \\ x_{ij}, d_m^-, d_m^+ \ge 0, (m = 1, \cdots, 4) \end{cases} \tag{8}$$

In the constraint condition, containing d_m^+ means that it is allowed to fail to reach the target value, containing d_m^- means that it is allowed to exceed the target values, and containing $(d_m^+ + d_m^-)$ means that it exactly reaches the target value. Our objective function minimizes the weighted sum of the positive and negative deviations of all constraints, and restricts the second index of all aspects in different degrees. For example, the constraint condition containing $0.7x_{31} - x_{32}$ means that China's food output should meet at least 70% of the food demand of the national population, but it is allowed to meet the food demand of more residents [17-18]. Therefore, the constraint condition uses the negative deviation variable d_3^-.

Sustainability is on the first floor, so we assign to it a priority factor P_1. Equity is on the second floor, so we assign to it a priority factor P_2. Efficiency and profitability are on the third floor, so we assign to it a priority factor P_3, and we believe that the constraints of efficiency are 2 times more important than the constraints of profitability, so their internal weight is also a 2 times relationship.

Table 5. The second grade indexes weight of food system (Goal programming model, China)

Second grade indexes	AGGE (x_{11})	RWCAU (x_{12})	TRW (x_{13})	ORWC (x_{14})
Optimized solution	641.38	1572.39	71829.12	2705.25
Second grade indexes	UPCL (x_{21})	RPCALA (x_{22})	PAEGE (x_{23})	TGP (x_{31})
Optimized solution	0.05	0.12	0.06	6.42
Second grade indexes	THDG (x_{32})	CFP (x_{41})	PGP (x_{42})	IGP (x_{43})
Optimized solution	4.26	2.11	0.62	1.86

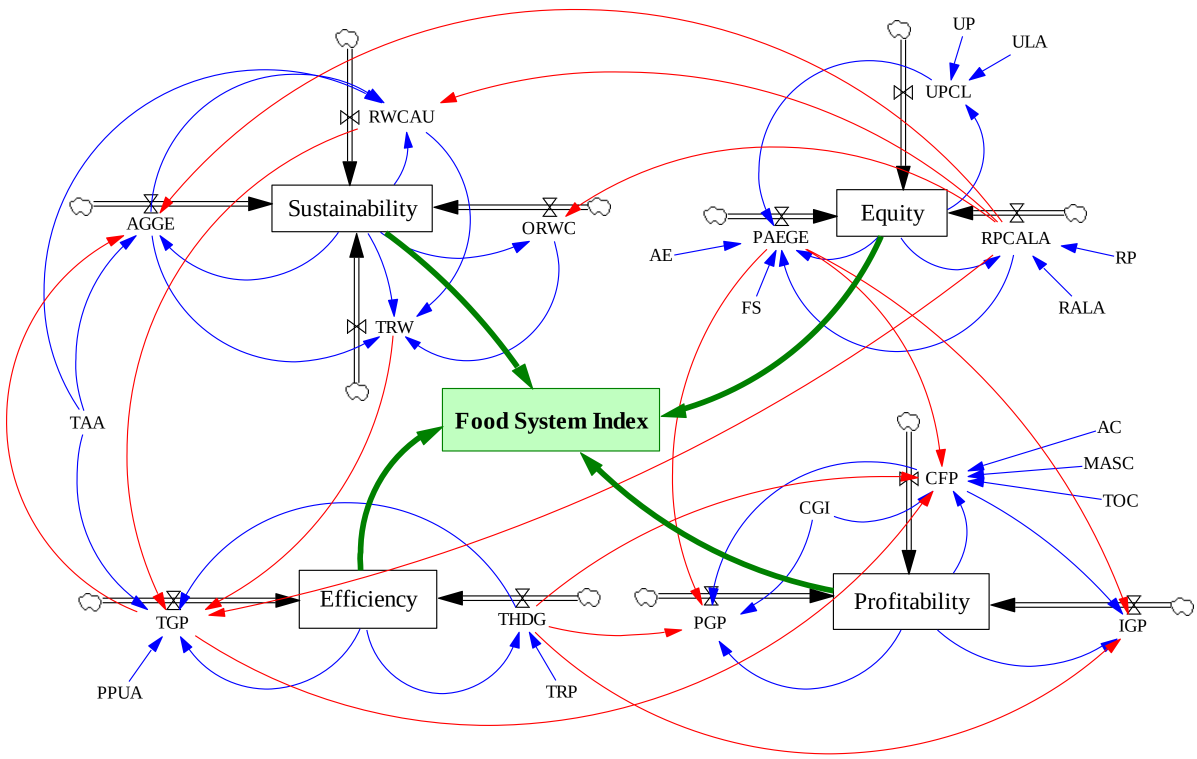

Figure 6. System dynamics analysis of food systems (Vensim)

4.2 Finding the Comprehensive Optimized Level

Next, we can repeat the method provided in the Section 4.1. By changing the priority of efficiency, profitability, equity and sustainability, we can gain the optimized solution data of the group $A_4^3 = 24$. But with only the optimized solution data, we cannot judge which priorities make the food system work best.

Therefore, we get inspiration from the Gini Coefficient and put forward the concept of comprehensive optimized index (COI) by rewriting Formula (1) to evaluate the effect of the food system. We believe that the larger the COI value is, the more the food system equipped with corresponding priority should be adopted. This is an evaluation method for the optimized system synthesis. Its calculation formula is:

$$COI = 100 \times \sum_{j=1}^{n} \pm\omega_i \widetilde{u_i} \tag{9}$$

Among them, the reason for containing " $\pm$ " is that some second indexes have a positive effect for the whole system, while some second indexes have a negative effect. As for negative effects, we can't simply add the COI. $\widetilde{u_i}$ represents the dimensionless data obtained by min-max normalization method. Its calculation formula is shown in Formula (10):

$$\widetilde{u_i} = \frac{x_i - min_{1\le i\le n}\{x_j\}}{max_{1\le i\le n}\{x_j\} - min_{1\le i\le n}\{x_j\}}, \widetilde{u_i} \in [0,1] \tag{10}$$

Therefore, the range of COI should be:

$$COI \in [100 \times Sum\ of\ negative\ index\ weights, 100 \times Sum\ of\ positive\ index\ weights] \tag{11}$$

According to the weights of the second indexes obtained in Section 3.1, the interval value of COI in this paper is between -38.75 and 61.25. We believe that the food system whose COI value is closer to the right endpoint is optimized at the comprehensive level, on the contrary, it is considered the worst. Additionally, in practice, we can't get the left and right endpoint value, we can only get to them indefinitely.

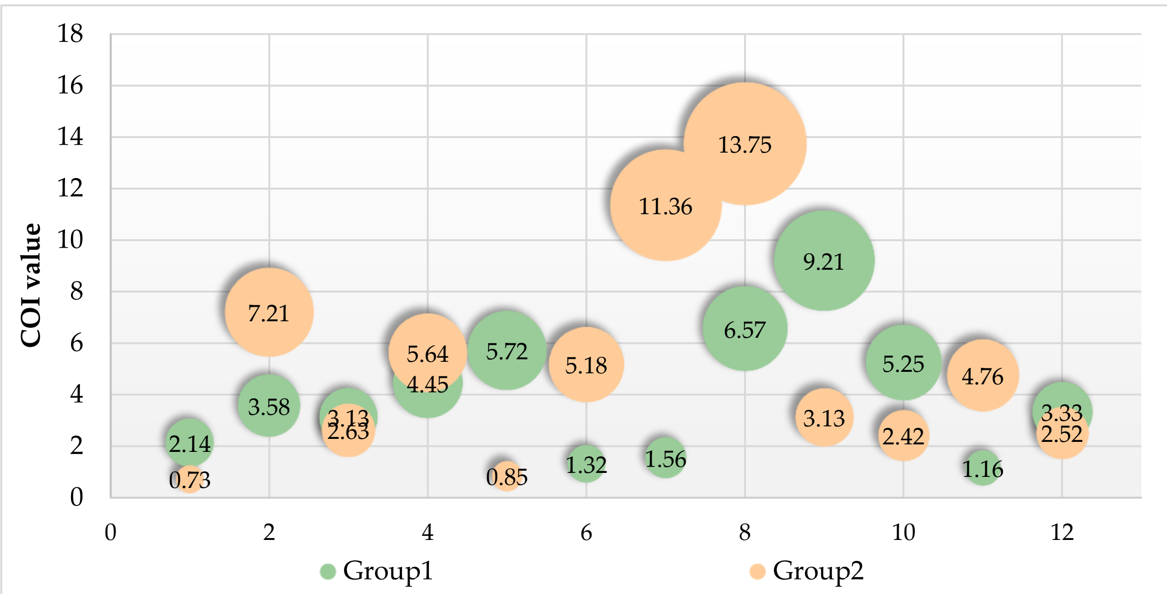

Figure 7. Bubble chart of COI values (China, see **Appendix A** for priority of grouping details)

By drawing the heat map of COI value (as shown in Figure 7), we clearly show which priority of food system allocation is the most comprehensive optimized. **The sequence from high to low is: efficiency, equity, profitability, sustainability** and COI_{China} is equal to 13.75 .

4.3 Time Estimation to Realize the Comprehensive Optimized Level

As for the estimation method of the time to reach a certain level, we have given a complete solution method in the Section 3.4, and do not give unnecessary details here. We directly refer to the optimized value in Table 5 to give the linear function results of the fitting curve (see Table 6).

Table 6. One-order function expression of index change curve fitting (China)

Second grade indexes	Functional expression	Results (x)	Time required (years)
RWCAU (x_{12})	$f_{12} = -51.95x + 2080$	9.8	4.8
UPCL (x_{21})	$f_{21} = 0.004231x + 0.01622$	8.0	3.0

For indexes that cannot gain the fitting results, we still make a rough estimation with $5-15$ years, and the calculation formula is:

$$T'_{min-China} = \frac{4.8+3+5}{6} \approx 2.1\ (years) \tag{12}$$

$$T'_{max-China} = \frac{4.8+3+15}{6} \approx 3.8\ (years) \tag{13}$$

Therefore, it will take at least two to four years for China to reach the comprehensive optimized level of the food system.

4.4 Differences Between the Benefits and Costs of a Food System: The Case of USA and China

In the previous section, we used the objective programming model with priority factors to realize the comprehensive optimization of the food system, and took China as an example to solve the model. In this section, we hope to intuitively evaluate the benefits and costs of a food system. But the results for only one country lack comparison and cannot explain the practical significance of the size of the numerical value. Therefore, we took USA as an example to solve the model, and the thermal map of the result is shown in Figure 8 [3-4]. At the same time, we choose a developing country and a developed country, which will make the comparison more intense and facilitate our analysis.

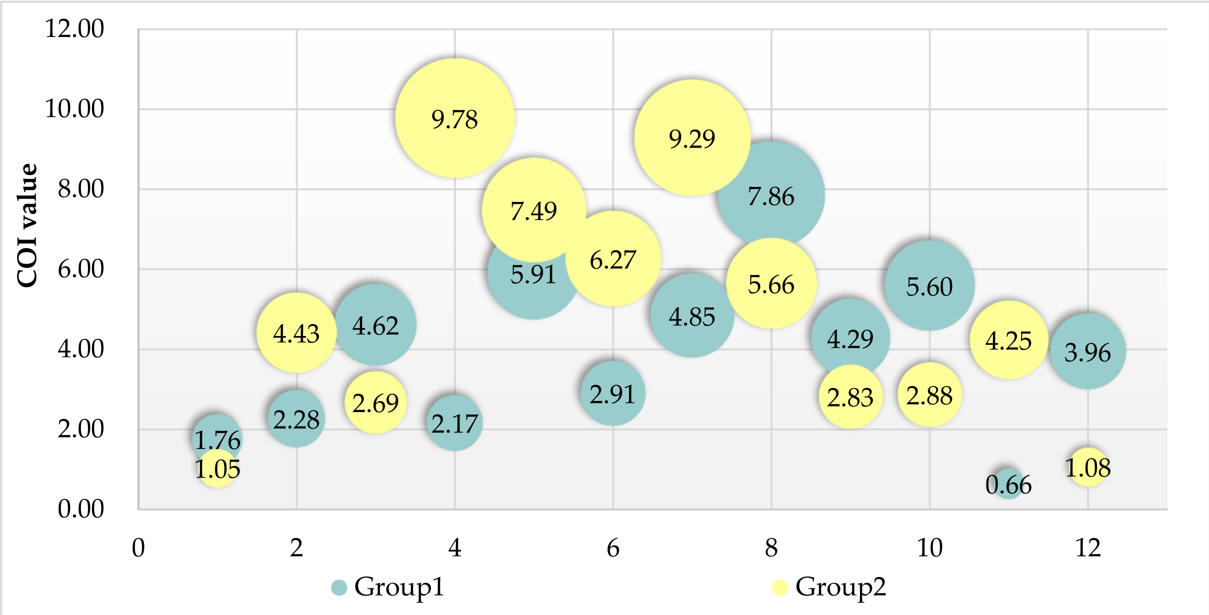

Figure 8. Bubble chart of COI value (The United States)

According to Figure 8, we can find that **the sequence of the optimized priority of the American food system from high to low is: efficiency, profitability, equity, sustainability** and COI_{USA} is equal to 9.78.

In economics, the Pareto Optimization Principle provides a strict criterion for equity and efficiency decision-making. Where, under the Pareto optimization standard of production and exchange, the slope of the product conversion curve is equal to the slope of the consumer's indifference curve. The consumer pays according to the marginal utility of the commodity, and the producer prices according to the marginal cost of the commodity, this moment we reach the Pareto optimization and the fairest state. The mathematical representation of this process is:

$$MRT_{xy} = MRS_{xy} \tag{14}$$

Borrowing this concept, production is agricultural food production, exchange is market food trading. In the case of Pareto optimization, the equity of food production and exchange is ensured to a great extent.

We use the definition of Agricultural Investment Effectiveness Coefficient ($AIEC$) in agricultural economic management to evaluate the economic benefits of a country (region) food system [19]. The calculation formula of $AIEC$ is:

$$AIEC = \frac{The\ added\ value\ of\ agricultural\ gross\ output\ value}{Agricultural\ investment} \tag{15}$$

Based on the results obtained before, we can respectively calculate that the $AIEC$ value is 0.83 for China and 0.46 for USA. The comparative effect is shown in Figure 9. The results show that compared with USA, China's investment in agricultural reproduction can achieve greater economic benefits, which may be due to the rapid expansion of agricultural scale caused by China's vigorous implementation of the strategy of "poverty alleviation" [20].

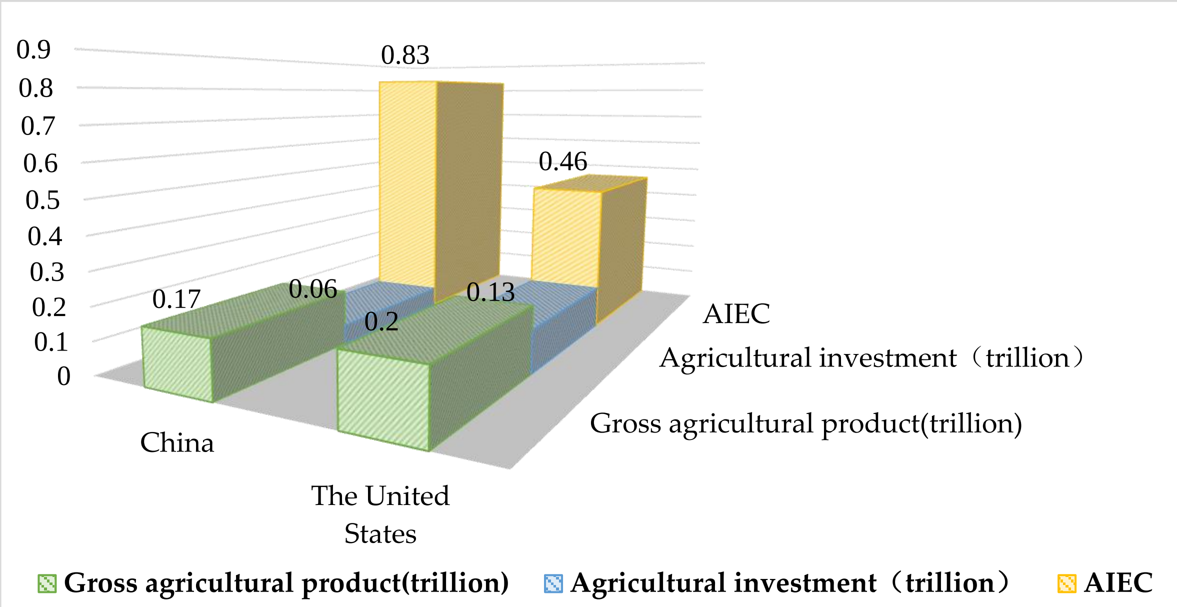

Figure 9. The comparison of gross agricultural product, agricultural investment and $AIEC$ value between China and the United States

5 Sensitivity Analysis

Here, based on the objective programming model with priority factors established in Chapter 4, we carry out sensitivity analysis under different scale food systems. Our analysis includes two parts: scalability analysis and adaptability analysis.

5.1 Scalability Analysis

We may face food systems of varying scale, ranging from a single state, province, region, etc. of a certain country to a massive system on a global scale. In the face of this situation, it is necessary for us to adjust the model, including the modification of the model index system and constraint conditions.

For example, if a model used to evaluate the scope of a country wants to be migrated to a larger scale, the complexity of the evaluation that we considered need to include more indexes. If we want to migrate to a smaller scale, we need to remove some indexes because some indexes are hard to measure, or even impossible to measure. Additionally, if we want to expand to a larger scope, we need to weaken the constraints. If we want to narrow down to a smaller range, we need to tighten the constraints. The schematic diagram is shown in Figure 10.

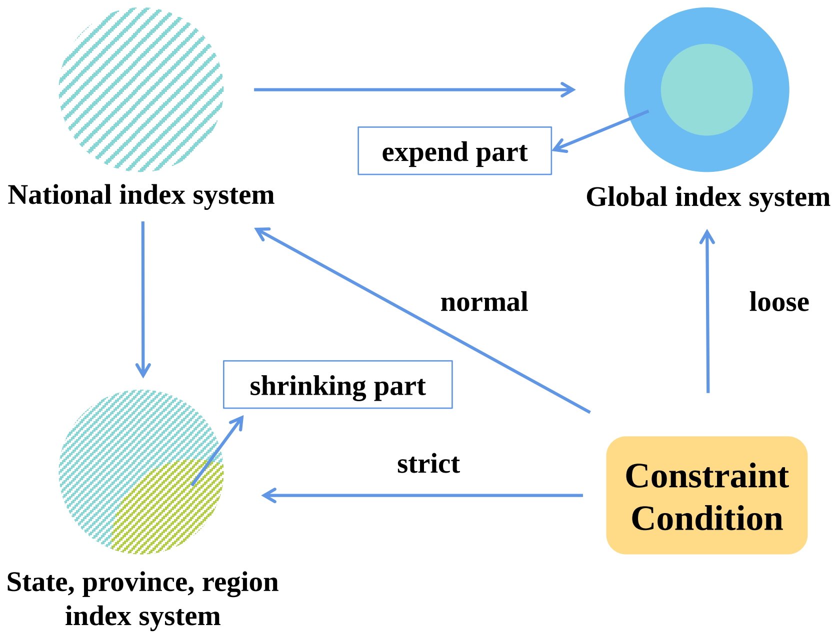

Figure 10. Expansion method of objective programming model

5.2 Adaptive Analysis

We select the step size as 10 and 0.1 respectively to change the parameters of the first two constraint conditions in the target planning model, and evaluate the COI value of each model. The sensitivity analysis results of the model are shown in Figure 11.

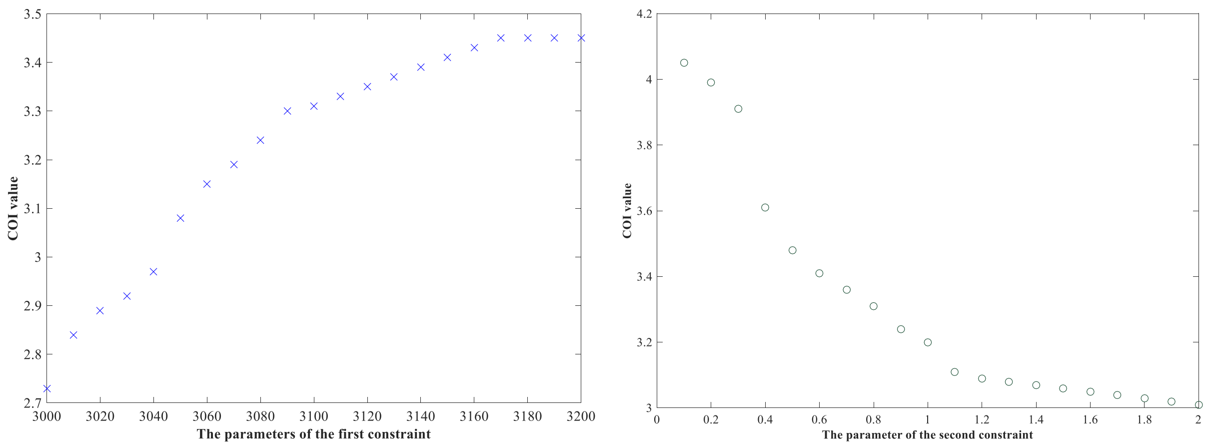

Figure 11. The change curve of COI value of the model with constraint parameters

It can be seen from the figure above that the turning point occurs when the parameter values are 3160 and 1.2 respectively. Additionally, as the first constraint parameter increases, the COI value keeps increasing and tends to be stable. As the second constraint parameter decreases, the COI value keeps decreasing and tends to be stable.

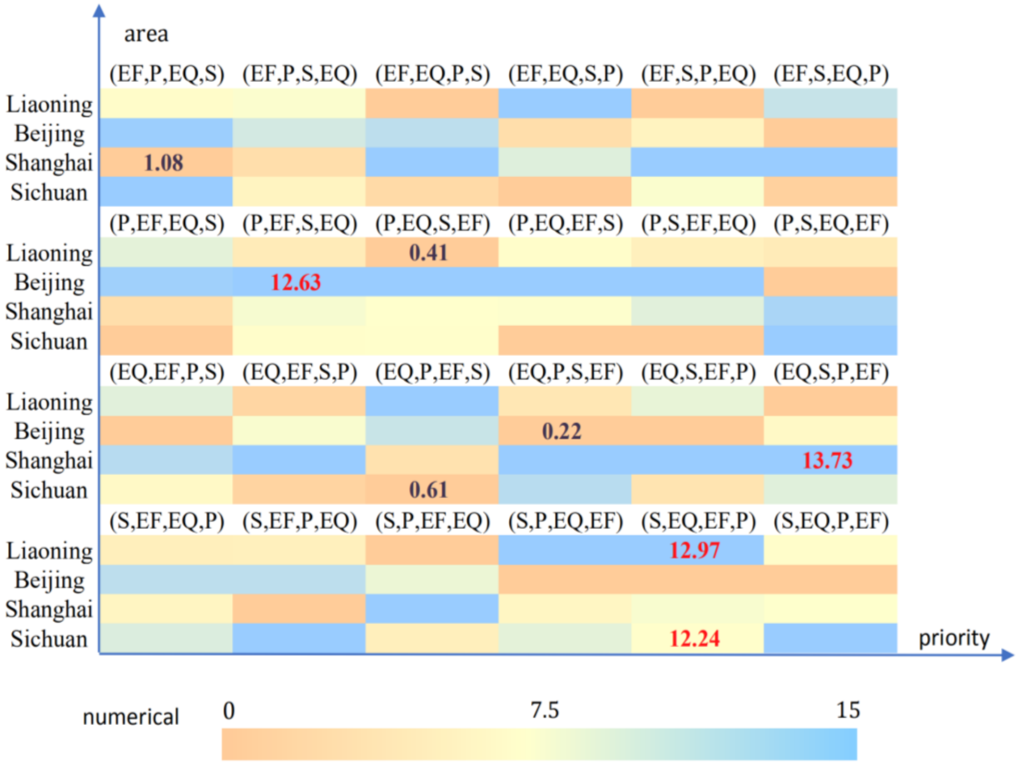

Figure 12. COI Heat Map of Four Cities in China (Liaoning Province, Beijing, Shanghai, Sichuan Province)

Next, we hope to apply the model to smaller regions in conjunction to integrate with a smaller food system. We selected four representative cities in China: Liaoning Province (with a total area of 148000 square kilometers), Beijing (with a total area of 16410 square kilometers), Shanghai (with a total area of 6340.5 square kilometers) and Sichuan Province (with a total area of 486000 square kilometers). Additionally, we adjusted the indexes of the food system and deleted the agricultural greenhouse gas emission (x_{11}). Therefore, this index cannot be measured in a small range and this data is not obtained.

Therefore, we use the target programming model with priority factors to solve the four regions respectively, and plot the COI value as a heat map (as shown in Figure 12). The results show that our model is also applicable to food systems in small regions.

6 Strengths and Weaknesses

6.1 Strengths

1. **The linear programming model is more convenient.** The model has a unified algorithm, we only need to modify the program parameters, we can complete the modification of the objective function and constraints.

2. **Goal programming model can realize the flexible adjustment of priority.** The model has priority factors and supports the optimization of multiple objectives, so the decision maker can decide which priority to adopt to optimize the food system.

3. **The COI value can provide a direct reference for decision makers.** Because the COI value shows which food system with the highest priority is optimized, the decision maker can choose the priority with the highest COI value, thus achieving comprehensive optimization.

6.2 Weaknesses

1. **Linear programming models may have no solutions.** Because the programming problem is strict for the objective function and constraint conditions, there may be no solution in the feasible region.

2. **Goal programming model has certain subjectivity and fuzziness.** The selection of objective function and weight is formulated under the subjective judgment of users, so it has a certain subjective color. We can reduce this subjectivity to some extent by using expert ratings.

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Appendix

Appendix A

Table 1-1. Detailed introduction of food index system

First Grade Index	Symbolic Snotation	Second Grade Index	Symbolic Notation	Unit	Effect	Note
Sustainability	x_1	Agricultural greenhouse gas emissions (AGGE)	x_{11}	(Tg CO_2)	-	year
		Renewable water consumption for agricultural use(RWCAU)	x_{12}	(billion cubic meters)	-	year
		Total renewable water (TRW)	x_{13}	(billion cubic meters)	+	year
		Other renewable water consumption (ORWC)	x_{14}	(billion cubic meters）	-	year
Equity	x_2	Urban per capita land area (UPCL)	x_{21}	hectare / ten thousand people	+	year
		Rural per capita arable land area (RPCALA)	x_{22}	hectare / person	+	year
		The proportion of agricultural expenditure in government expenditure (PAEGE)	x_{23}	%	+	year
Efficiency	x_3	Total grain production (TGP)	x_{31}	million tons	+	year
		Total household demand for grain (THDG)	x_{32}	million tons	-	year
Profitability	x_4	Cost of food production (CFP)	x_{41}	trillion dollars	-	unit area
		Profit from grain production (PGP)	x_{42}	trillion dollars	+	unit area
		Investment in grain production (IGP)	x_{43}	trillion dollars	+	unit area

Table 1-2. Priority grouping (Group 1)

1	2	3	4	5	6	7	8	9	10	11	12
(EF,P, EQ,S)	(EF,P, S,EQ)	(EF,EQ, P,S)	(EF,EQ, S,P)	(EF,S, P,EQ)	(EF,S, EQ,P)	(P,EF, EQ,S)	(P,EF, S,EQ)	(P,EQ, S,EF)	(P,EQ, EF,S)	(P,S,EF, EQ)	(P,S, EQ,EF)

Table 1-3. Priority grouping (Group 2)

1	2	3	4	5	6	7	8	9	10	11	12
(EF,P, EQ,S)	(EF,P, S,EQ)	(EF,EQ, P,S)	(EF,EQ, S,P)	(EF,S, P,EQ)	(EF,S, EQ,P)	(P,EF, EQ,S)	(P,EF, S,EQ)	(P,EQ, S,EF)	(P,EQ, EF,S)	(P,S,EF, EQ)	(P,S,EQ ,EF)

Appendix B

MATLAB Program: Linear Programming Model Solving (China)

```
c=[0.0571;0.0839;0.0927;0.0378;0.0558;0.0579;0.0914];
a=[0,1,-0.1,1,0,0,0;0,0,0,0,-1,1,0;1,0,0,0,0,0,0;0,1,0,0,0,0,0;0,0,0,0,-1,1,0];
b=[-700;5;700;0.08;0];
aeq=[0,1,0,1,0,0,0];
beq=6000
[x,y]=linprog(-c,a,b,aeq,beq,zeros(7,1))
```

LINGO Program: Objective Programming Model Solving (China)

```
model:
sets:
level/1..3/:p,z,goal;
variable/1..2/:x;
h_con_num/1..1/:b;
s_con_num/1..4/:g,dplus,dminus;
h_con(h_con_num,variable):a;
s_con(s_con_num,variable):c;
obj(level,s_con_num)/1 1,2 2,3 3,3 4/:wplus,wminus;
endsets
data:
ctr=?;
goal=? ? 0;
b=12;
g=1500 0 16 15;
a=2 2;
c=200 300 2 -1 4 0 0 5;
wplus=0 1 3 1;
wminus=1 1 3 0;
enddata
min=@sum(level:p*z);
p(ctr)=1;
@for(level(i)|i#ne#ctr:p(i)=0);
@for(level(i):z(i)=@sum(obj(i,j):wplus(i,j)*dplus(j)+wminus(i,j)*
dminus(j)));
@for(h_con_num(i):@sum(variable(j):a(i,j)*x(j))<b(i));
@for(s_con_num(i):@sum(variable(j):c(i,j)*x(j))+dminus(i)-dplus(i
)=g(i));
@for(level(i)|i #lt# @size(level):@bnd(0,z(i),goal(i)));
end
```