Research on Grain System Evaluation and Optimization Based on Entropy Weight Method

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Abstract. Owing to the unstable food system nowadays, it is urgent to establish a new food system that is robust enough, so we established the current food system scoring model based on 21 indicators at three levels: economy, environment, and food & nutrition. Then normalize the corresponding data of each indicator, and use DEA and entropy weight method(EWM) to calculate the weight to quantify the score of the food system. When strengthening the consideration of sustainability and equity, we use the grey correlation method to analyze the correlation coefficients between sustainability, equity and the main indicators, then get the optimized score. In addition, we introduced Holt's two-parameter exponential smoothing time series analysis model to predict the development trend of the score of the existing system and the enhancement system, and determine the time required for enhancement to produce a certain effect.

Keywords: Food System; EWM; Time Series Analysis; Evaluation and Optimization.

1. Introduction

As an indispensable strategic material related to the survival and development of more than seven billion people, the food issue has always been the focus of attention of governments and academic circles. The global food market has entered a period of extreme instability after 2006 [1], which is inseparable from our current global food system that prioritizes efficiency and profitability. This system that allows relatively cheap and efficient food production and distribution ignores the importance of the environment and is not conducive to the sustainable development of human society and the entire planet.

Today, 820 million people in the world are still suffering from hunger, and about 2 billion people are facing moderate or severe food insecurity [2], and there is no room for optimism in terms of various nutritional indicators. Moreover, the current food system leaves a massive environmental footprint accounting for "29% of greenhouse gas emissions, …, up to 80% of biodiversity loss, 80% of deforestation, and 70% of all freshwater use [3]." Meeting increasing demand for nutritious food for a growing global population under climatic pressures, while mitigating associated environmental damages, is already a pressing challenge [4].

According to this issue, we must establish a new and sufficiently robust food system so that it can be optimized from various levels of efficiency, profitability, sustainability, and Equity. Based on the entropy weight method, a scoring model for the food system under more than 20 indicators was established, and the existing global data was used to calculate the current food system score. Next, we optimize the existing food system to achieve equity and sustainability, compare the food system before and after optimization and predict how long it will take to achieve.

2. The Current Model of Food System

2.1 Model Establishment: A Scoring Model Based on Economic Benefits

2.1.1 Index Selection

The current food system prioritizes efficiency and profitability, which will cause a certain degree of damage to the environment and human society. We have established the current food system with efficiency, profitability, environmental pollution, nutritional status, and food security as the main indicators, denoted as $a_i(i = 1,2,\ldots,5)$. Each main indicator which denotes as $a_{ij}(i = 1,2,\ldots,5, j = 1,2,\ldots,n)$has a corresponding sub-indicator. At the same time, we divide the indicators into positive indicators (efficiency, profitability) and negative indicators (environmental pollution, nutritional status, food security). The main indicators of food systems are as followed [5]:

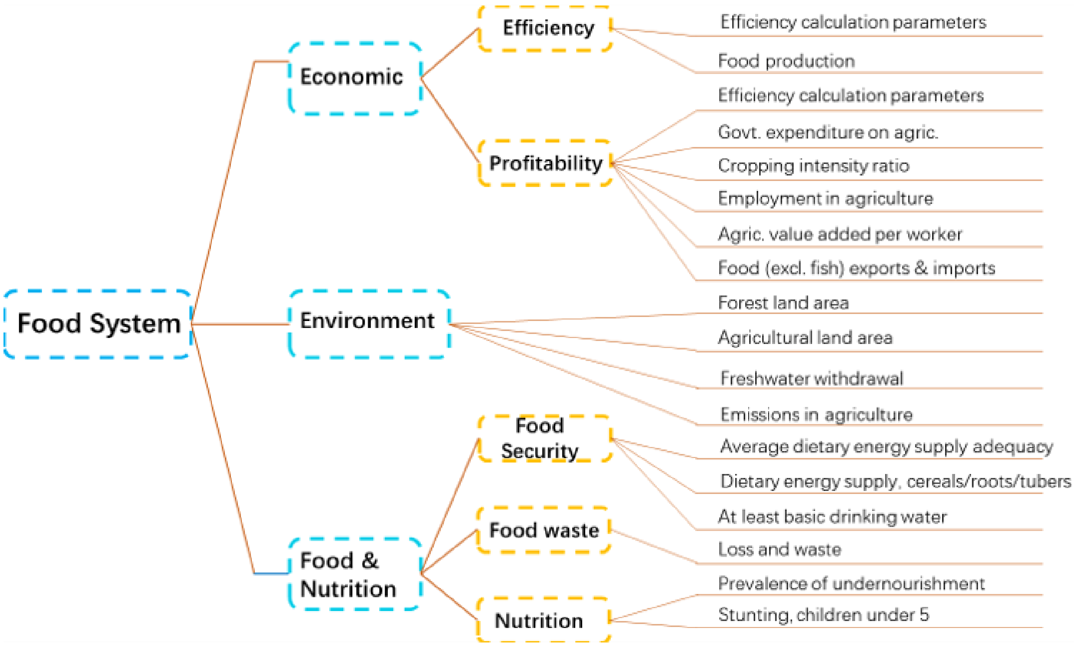

Figure 1. Main indicators of food system

2.1.2 Determination of Evaluation Index Weight

Index weight refers to the importance relationship of each indicator under the same objective constraint [6]. In the comprehensive evaluation of multiple indicators, weight plays a pivotal role. This paper uses the entropy coefficient method to assign weight to the food system evaluation indicators. The main steps are as follows:

1) Data numbering: Identify the information data of the m-th year of the index a_{ij} and record it as $a_{ij}^1, a_{ij}^2, \ldots a_{ij}^m$.

2) Data normalization processing:

Due to the influence of dimensions, it is not conducive to our analysis when establishing a scoring model. Therefore, data normalization is a reasonable choice, and its essence is to achieve assimilation analysis between data of different dimensions. X_{ij}^m is the normalized processing data of a_{ij}^m:

Positive index:

$$X_{ij}^m = \frac{a_{ij}^m - \min(a_{ij})}{\max(a_{ij}) - \min(a_{ij})} \tag{1}$$

Negative index:

$$X_{ij}^m = \frac{a_{ij}^m - \max(a_{ij})}{\max(a_{ij}) - \min(a_{ij})} \tag{2}$$

note: $i = 1,2,\ldots,n; j = 1,2,\ldots,m.$

3) Calculate the proportion of the $\boldsymbol{k}$-th sample under the $\boldsymbol{j}$-th index in the index:

$$p_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \tag{3}$$

4) Calculate the entropy value $\boldsymbol{e_i}$ of the $\boldsymbol{i}$-th index:

$$e_i = \frac{1}{\ln(n)} \sum_{j=1}^{m} p_{ij} \ln(p_{ij}) \tag{4}$$

5) Calculate the entropy redundancy $\boldsymbol{d_i}$ and the weight $\boldsymbol{w_i}$ of each index:

$$d_i = 1 - e_i$$
$$w_i = \frac{d_i}{\sum_{i=1}^{n} d_i} \tag{5}$$

2.1.3 Scoring Model

Based on this, we can establish a food system scoring model based on economic benefits, where S is the economic benefit food system score:

$$S = \sum_{i=1}^{5} \sum_{j=1}^{m} w_j X_{ij} \tag{6}$$

2.2 Test of Model

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$$S = \sum_{i=1}^{5} \sum_{j=1}^{m} w_j X_{ij} \tag{7}$$

2.2.1 Index Selection and Model Analysis Based on Efficiency

Based on the principles of scientific, comparability, representativeness, and accessibility of data, and comprehensively considering the actual situation of agricultural input and output, we select 11 indicators. The input indicators are: total sown area of crops $x_1(1000hm^2)$, effective agricultural irrigation area x_2 $(1000\,hm^2)$, agriculture, forestry, animal husbandry and fishery employees $x_3(10k$people), fixed asset investment in agriculture, forestry, animal husbandry and fishery $x_4(10k$ yuan), financial support for agriculture x_5 ($10k$ yuan), total agricultural machinery power x_6 ($10kW$), rural electricity consumption x_7 ($10kW \cdot h$), agricultural fertilizer application $x_8(10k$tons); output indicator: The total output value of agriculture, forestry, animal husbandry and fishery is $y_1(10k$yuan), and the added value of agriculture, forestry, animal husbandry and fishery is $y_2(10k$yuan) [7].

We collected annual data information for these indicators. Considering the large amount of data, it needs to be processed appropriately.

We introduce the DEA model to analyze the input and output of efficiency data.DEA models include,$\mathrm{C^2R}$, BCC, F , ST and $\mathrm{C^2W}$.We use the $\mathrm{C^2R}$ model to analyze the problem, the model is:

$$\min\ \theta$$
$$\text{s.t.}\begin{cases} \sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- = \theta x_{i0} \\ \sum_{j=1}^{n} \lambda_j y_{mj} - s_m^+ = y_{m0} \\ \lambda_j \geq 0, j = 1,2,\dots,n \\ s_i^- \geq 0, s_m^+ \geq 0 \\ i = 1,2,\dots,r; m = 1,2\dots,t \end{cases} \tag{8}$$

where: n is the number of decision-making units DMU. r, t are the number of input and output types respectively. x_{ij} is the input of the j-th decision-making unit to the i-th type of input; y_{mj} is the output of the j-th decision-making unit to the m-th type of input; s_i^- and s_m^+ are slack variables, respectively representing the input redundancy and output Insufficient amount; λ_j is the combined proportion of the j-th decision-making unit DMU in an effective DMU combination reconstructed from the DMU; θ is the relative efficiency value of the decision-making unit.

We will substitute the relevant data information (2010-2019) obtained from FAO into the C^2R model and perform programming operations. The results are as follows:

Table 1. The results of Efficiency

DMU	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
θ	1	1	1	1	1	0.951	0.993	0.997	0.974	1

It can be seen from table 1 that the DEA is effective from 2001 to 2014 and 2019, and its efficiency (A) is both 1, that is, the input redundancy and the output shortfall are both 0, indicating that the input-output efficiency in the past five years has reached the maximum Excellent; from 2015 to 2018, it was non-DEA effective, with varying degrees of input redundancy and insufficient output, but the efficiency was above 0.95. Overall, the global agricultural input-output efficiency is developing in a positive direction.

In summary, the model we have established can truly reflect the efficiency and profitability of the current food system.

2.2.2 The Result of the Model

According to the above model, we substitute the collected data and get the scoring result as shown in the Figure 2 below.

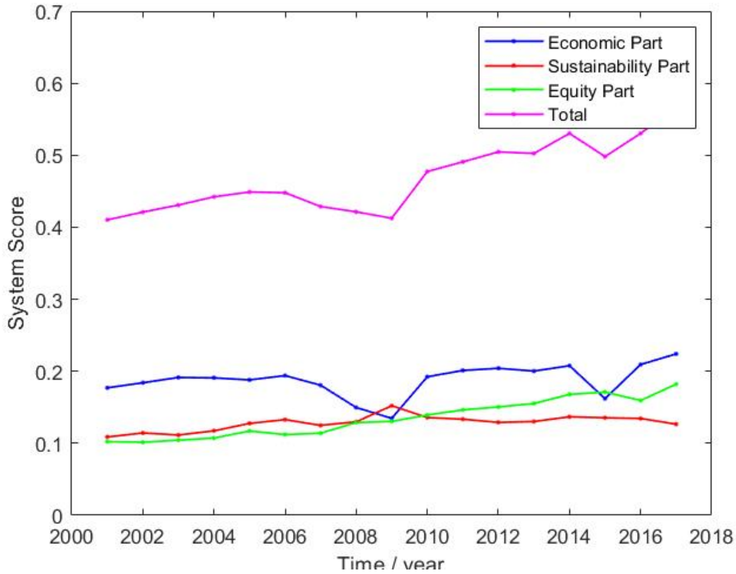


Figure 2. Scoring result of the model based on Efficiency and Equity

It can be seen from the results that although the evaluation score has a roughly linear growth trend in 20 years, the fluctuations and instability are high. This shows that the existing world food system, which is based on priority economic indicators such as efficiency and profit, is constantly developing, but it is very fragile and cannot play a very good role in guaranteeing emergencies.

3. The Consideration of Sustainability and Equity

As mentioned above, we consider the scoring model of the food system in today's reality. Based on the development trend of globalization and sustainability, we need to consider the sustainability and equity of food system.

3.1 The Importance of Sustainability and Equity

Sustainability refers to a process or state that can be maintained for a long time. The sustainability of human society is composed of three inseparable parts: ecological sustainability, economic sustainability and social sustainability. Adapted from FAO, 2014, we can conclude how sustainable food system will impact in three aspects, that is:

Figure 3. Impact of sustainable food system in three aspects

Based on the consideration of the actual situation, the environmental problems in the food production process in the food system are important issues that we need to consider. Corresponding protection needs to be increased for water pollution, land pollution, air pollution, energy use, and biodiversity in the food system. On this basis, the score of the food system will increase, which also means that when sustainability is added, the entire food system will be greatly improved, and it will have long-term good development.

3.2 Take Sustainability and Equity into Consideration

3.2.1 Correlation Analysis

When prioritizing the impact of sustainability and equity on the current food system, we first analyze the degree of correlation between sustainability and the three main indicators that assess the food system's environment, nutrition, and food security. Here we introduce the grey relational analysis method. The grey relational analysis method is based on the quantitative comparison of the development trend between the various factors in the system. It is a method to measure the degree of correlation between the factors by analyzing the similarity and dissimilar degree of the development trend. The closer the curve geometry of the evaluation object and the standard object, the closer its development trend, and the greater the degree of association.

The degree of association is essentially the difference between the geometric shapes of the curves, and the difference between the curves can be used as a measure of the degree of association[8]. For the reference sequence X_0, corresponding to the sustainability and equity, there are n comparison sequences $X_p(p = 1,2, \dots, n)$.The comparison order of the correlation coefficient of X_i and the reference order can be passed at any time The following formula is calculated:

$$\alpha_i = \frac{1}{N}\sum_{k=1}^{N}\frac{min + \mu max}{\Delta O_i(k) + \mu max} \tag{9}$$

In the formula, N is the total number; max, min are the maximum and minimum values in each comparison group, and the absolute difference calculation for each comparison group is recorded as $\Delta O_i(k)$. α_i is the correlation between the series of the correlation coefficient at each moment (each point in the curve) and the reference sequence. Since the number is greater than 1, and the information is too scattered, it is easier to compare the whole. Among them, μ is the coefficient, $0 < \mu < 1$, and the general value is 0.5, which is mainly to reduce the deviation caused by the maximum absolute difference and improve the significance between the objects.

3.2.2 Improved Evaluation Model

In the above analysis, we can get the correlation coefficients of sustainability, equity and main indicators as $\alpha_i, \beta_i (i = 1,2, \dots ,5)$. Since the food system considering sustainability still satisfies the scoring criteria of formula (4), based on the above discussion, we can establish a scoring model for the food system affected by sustainability and equity:

$$S = \sum_{i=1}^{5} \sum_{j=1}^{n} (\alpha_i + \beta_i) w_j X_{ij} \tag{10}$$

3.3 Take Sustainability and Equity into Consideration

Through the above model, we can get the scoring results after optimization of sustainability and equity indicators as follows:

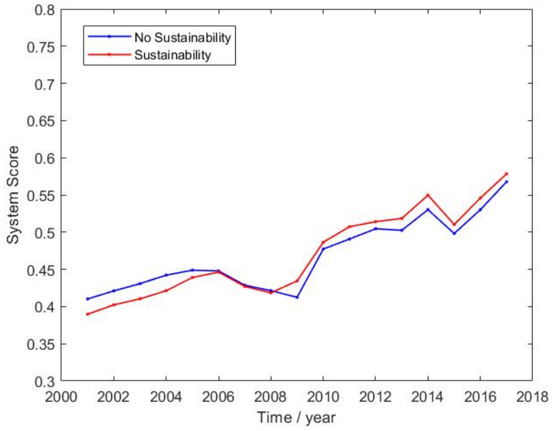


Figure 4. Scoring results after optimization

The blue curve represents the system score fluctuations without considering sustainability factors, and the red curve represents the system score fluctuations considering sustainability and equity factors. It can be clearly observed that the sustainable food system scores during the period from 2001 to 2008 was significantly lower than that without considering sustainability and equity. This is obviously reasonable, because sustainability and equity were invested at the very beginning. Equity factors will have a certain inhibitory effect on economic factors. Under the world food crisis from 2007 to 2009, sustainable and fair investment will bring positive effects, and gradually will have the same relationship with the economy and have a positive impact on the entire food system. Therefore, the model is more reasonable.

3.4 How long and When

According to the two score evaluation results obtained above, they are the scoring result under the current situation of the food system and the scoring result of the fair and sustainable index optimization. In this part, we hope to use the time series model to predict the score changes in the next six years on the basis of the score evaluation results, and reflect the effect of optimizing equity and sustainability factors by comparing the trend of score changes and the difference in growth rates between the two. At the same time, time series results are also used to distinguish when it will happen.

3.4.1 Time Series Model Construction

Based on the above trend chart and the ACF index in R language for testing, it can be seen that such a trend chart contains a more obvious linear trend, but there is no obvious periodicity. Therefore, the Holt two-parameter exponential smoothing method[9] is used for time series forecasting.

Under this model, a sequence with a linear trend can usually be expressed as the following model:

$$x_t = a_0 + bt + \varepsilon_t \tag{11}$$

Among them, a_0 is the intercept;$b$is the slope; ε_t is the random fluctuation, $\varepsilon_t \sim N(0, \sigma^2)$. This model can be expressed as the following recurrence formula:

$$\begin{cases} x_t = a(t-1) + b(t) \\ a(t-1) = x_{t-1} - \varepsilon_{t-1} \\ b(t) = b + \varepsilon_t \end{cases} \tag{12}$$

In actual calculations, the Holt two-parameter exponential smoothing method is to use the simple exponential smoothing method respectively to continuously smooth the intercept term $\hat{a}(t)$ and the slope term $\hat{b}(t)$. The recurrence formula is as follows:

$$\hat{a}(t) = \alpha x_t + (1-\alpha)\left[\hat{a}(t-1) + \hat{b}(t-1)\right] \tag{13}$$

$$\hat{b}(t) = \beta[\hat{a}(t) - \hat{a}(t-1)] + (1-\beta)\hat{b}(t-1) \tag{14}$$

where,α, β are smoothing index, $0 < \alpha, \beta < 1$.

In the Holt two-parameter exponential smoothing method, the predicted value for the previous k periods are:

$$\hat{x}_{t-1} = \hat{a}(t) + \hat{b}(t)k, \forall k \geq 1 \tag{15}$$

3.4.2 Display of Calculation Results

1) The current score prediction results under the food system are shown in Table 2. The visualization results are shown in the Figure 5(a).

Table 2. The current score prediction results

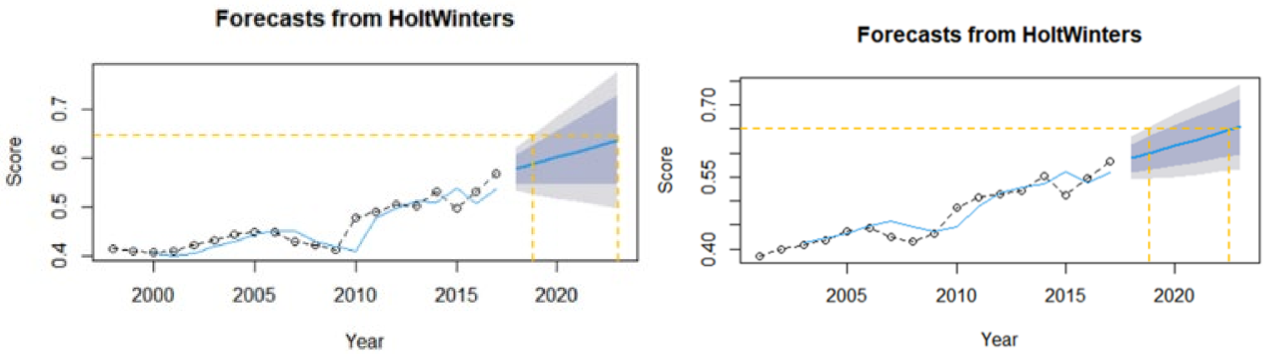
Smoothing parameters	α: 0.923	β: 0.142
Coefficients	$a(t) =$ 0.5653	$b(t) =$ 0.011897

2) The results of fair and sustainable index optimization scoring forecast are shown in Table 3. The visualization results are shown in the Figure 5(b).

Table 3. The results of fair and sustainable index optimization scoring forecast

Smoothing parameters	α: 0.7549	β: 0
Coefficients	$a(t) =$ 0.5764	$b(t) =$ 0.0130

It can be seen from the results that although the food system after optimizing sustainability and equity is not as good as the existing food system in the first few years (in our opinion, this is normal for sacrificing part of the economic benefits after increasing investment in environmental protection and fair distribution) Phenomenon), but in the 5th year or so, the scoring showed a benefit relative to the existing system, which is reflected in the overall rate of scoring and the stability of the model.



(a) (b)

Figure 5. The visualization results

At the same time, the time series method is used to predict the expected results of the change trend of the score. As shown in the Figure 5, the growth trend of the optimized score is significantly better than the existing model. For example, under the 95% confidence level, the lower limit of confidence still shows a positive growth in the optimized model, while the existing model shows a negative growth. In addition, we use 0.65 as the target optimization score. Reaching this score indicates that sustainable and fair optimization has produced a certain effect. In the optimized model, the Point Forecast values are 0.5894, 0.6024, 0.6154, 0.6284, 0.6414, and 0.6544 from 1 to 6 years, and the predetermined target can be achieved between the fifth year (2022) and the sixth year (2023).

3.5 Sensitivity Analysis

We conduct sensitivity analysis on the model to judge the rationality of our model. Increase the index by 5% and observe the trend of the new scoring data of the food system scoring model.

As shown in the figure, we can see that with a 5% increase, the new scoring data from 2001 to 2017 coincides with the change trend of the original scoring data close to 100%. It shows that the changes in subsequent data have little effect on the rationality of our food system scoring model, that is, our food system scoring model has good rationality and applicability.

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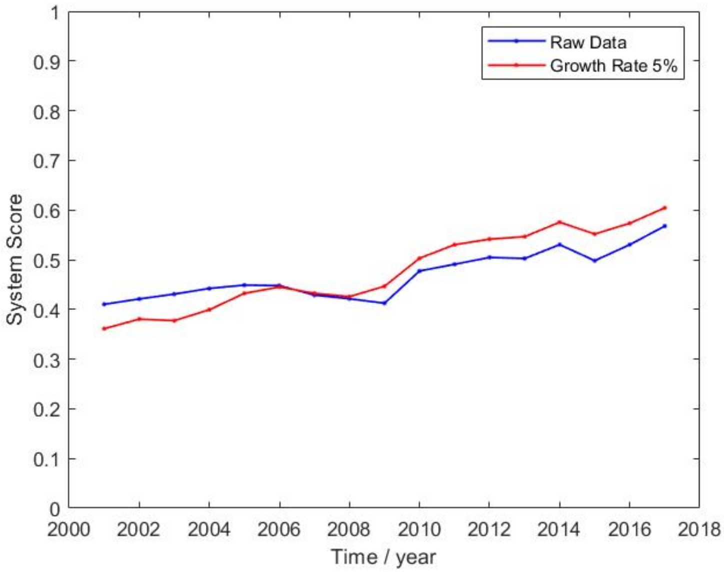

Figure 6. Sensitivity analysis of the model

4. Strengths & Weaknesses

4.1 Strengths

The food system scoring model and optimization model are both considered based on multiple indicators. The larger the scope of consideration, the more reasonable, scientific, and scalable models can better reflect the actual situation.

Able to make reasonable priority judgments for different countries according to their national conditions to optimize the structure of the food system.

The scoring model and optimization model can judge the future based on existing data and are forward-looking.

4.2 Weaknesses

Many indicators have higher requirements for data integrity and processing.

The forecast of the future does not take into account the impact of serious emergencies.

5. Conclusion

We established a comprehensive index food system scoring model. It is divided into two steps, first consider the current food system scoring model, and then consider the new food system scoring model of the ability and equity factors. Use DEA and entropy weight method to normalize and weight the data to quantify our scoring of the food system model. After processing the actual data, we compare the data changes of the two scoring models, which can show that the consideration of sustainability and equity is added, and the overall system is expected to have a good optimization effect. After time series analysis, the model can also predict the future food system score.

This sudden outbreak of the epidemic has had a great impact on the world and brought about a new round of world food crisis. The reduction or closure of exports by countries has exacerbated the disaster of the world food crisis. In our model considerations, we should give priority to equity and justice, and overcome difficulties together in order to survive this crisis. The overall structure of the food system can also develop more rationally and achieve true sustainability.

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