Problem Chosen	2021 MCM/ICM Summary Sheet	Team Control Number
E		**2113502**

Power Food System! From Now to Future

Summary

In our article, the optimization of the entire food system is divided into three parts. From the **assessment** of the food system to **optimization**, to the **forecast** of the long-term and short-term effects of measures on the food system.

In the evaluation part of the food system, with the expansion of the connotation and extension of the concept of the food system, single indicators such as grain production can no longer fully reflect the food security status, which makes the **multi-indicator comprehensive evaluation method** an effective tool for food system evaluation. We first **analyze the correlation** of the variables to be analyzed, and then we use the **entropy method** to determine the weight of **efficiency, profitability, sustainability, and equity** in the existing food system. According to the characteristics of entropy, use entropy to determine an indicator The greater the degree of dispersion of the index, the greater the influence (weight) of the index on the comprehensive evaluation. We found that the efficiency and profitability of the existing food system have a higher weight. Next, the average temperature, average precipitation, and other data are reduced by principal component analysis, to calculate the efficiency index and profitability index of each country. For measuring the equity in the food system, we refer to the Gini coefficient to measure the gap between the rich and the poor. In the method, the per capita food Gini coefficient is established.

In the process of optimizing the food system, we proposed three methods. First, we optimize the trade process of the food system. In order to re-optimize the food system and improve fairness. We classify countries or regions into suppliers, transfers, and receivers, establish a food trade network, and use the **maximum flow algorithm** to find the largest food supply in the network, in order to achieve a fairer distribution and reduce food waste and to meet as much as possible Food needs of many countries or regions. Next, we simulated the establishment of an agricultural joint organization between regions to improve food production technology and use the **Shapley method** for fair distribution within the organization. Whether in developed or developing countries, these methods can significantly increase food production over a long period, reduce the level of food storage, reduce food waste in the storage process, reduce greenhouse gas emissions, and improve the sustainability index.

In order to detect the short-term and long-term effects of our method, we analyzed the future changes in total grain output and sustainability index through the method of moving smooth autoregressive. We analyzed the cost of changing the input of the food system in the short term. In the long term, it can obtain greater benefits, and the efficiency, profitability, sustainability, and equity can be improved.

Finally, we discussed the **scalability** and **adaptability** of the model. Thanks to the wide application of our method, our model can be used in more situations.

Keywords: Food System; PCA; Optimization; Multi-indicator Comprehensive Evaluation; Entropy; maximum flow algorithm

Contents

1 Introduction

1.1 Problem Background

Food is the basic necessities of human life, and it is also an important material basis for ensuring the sustainable development of mankind. The food system is a complex network of activities involving the four processes of production, transportation, consumption, and obtaining nutrition. These processes involve complex or visible or transparent elements. It is generally measured in four aspects: efficiency, profit, fairness, and sustainability. These four aspects are reflected in the basic indicators of the four processes of production, processing, transportation, and consumption in the food system.

The current global food system is composed of large-scale national and international food producers and distributors. Although food can be produced and distributed relatively efficiently and cheaply, it also makes the fairness and sustainability of the food system unsatisfactory. The "2030 Agenda for Sustainable Development" prepared and released by FAO, WHO, UNICEF, and the Food Plan shows that the decline in the proportion of hungry people in the world that has been experienced for more than a decade has ended, the hunger index has risen again, and malnourished The incidence has risen to nearly 20% in Africa, more than 12% in West Asia and more than 820 million people in the world are still suffering from hunger. Today, world agriculture still faces major challenges. Including how to feed the growing world population, how to reduce rural poverty in the world, and how to manage the goods and services of the ecosystem following global environmental changes. In the past, the components of the food system were evaluated or analyzed in the research, focusing more on the efficiency and benefits of the food system, but the events that occurred in the past few decades have shown that a more comprehensive evaluation model and optimization means are needed To solve these complex problems, to better consider the fairness and sustainability brought by the system.

1.2 Our Work

First, establish a food system evaluation model. Principal component analysis and correlation analysis make a preliminary analysis of the acquired data, use the entropy weight method for evaluation, and calculate the Gini coefficient of food consumption to reflect the fairness of the food system.

Optimize the existing food system through three different methods. First, the existing food trade network was rearranged through the minimum cost and maximum flow algorithm. Consider establishing a regional agricultural cooperation organization to jointly develop agricultural technology, and adopt the Shapley value method for fair distribution within the organization.

Through the impact assessment of the above optimization methods. Use the Autoregressive moving average model to predict the future food system conditions and calculate short-term and long-term costs and benefits.

1.3 Flow Chart

Figure 1: Flow Chart

2 Assumptions and Notations

2.1 Assumptions

- We assume that the natural environment of each country will not change. That means we can see that it is constant. This assumption simplifies our analysis and is reasonable because the natural environment is usually stable.
- We assume that the policies of each country follow the current rules. This assumption may not exist in reality, but it is crucial for us to predict the future data of various countries.

- The impact of rare global natural disasters is not considered. The population growth rate and death rate will not change suddenly and drastically.

2.2 Notations

Table 1
Notations adopted in our paper

Notations	Description
t	Period index, $t = 1, 2, \ldots, T$
ftf_i	food trade factor
$k(u,v)$	k(u,q) means the flow from node u to v
$w(u,v)$	the weight of an edge from node u to v
$cost_i$	the cost of trade between two countries or regions
deg_i	the trade cost of a countries or regions
GS	Grain stock Index
GE	Grain Export Index
GI	Grain Import Index
GU	Food utilization Index
FC	Forest Cover Index
CE	CO2 emission per capita Index

3 Food system evaluation model

3.1 Index Selection

For the evaluation indicators of efficiency, since the food system is a complex network of activities involving the four processes of production, transportation, consumption, and obtaining nutrition, we specifically consider the indicators involved in efficiency from these four processes. In terms of production and transportation, we have collected grain_production, grain_yeild, grain_stock, grain_import from FAOSTAT for the past five years in 23 major countries based on the current internationally accepted indicators of food system efficiency. Besides, we should also consider that the agricultural production environment will also have a significant impact on agricultural production efficiency, including whether the temperature is suitable, whether the precipitation is suitable, etc. Because there are many indicators in this part and it is difficult to determine the positive and negative orientation of each indicator, we first pass PCA bundles the above-mentioned indicators to reduce the dimensionality and obtains a production suitability index, which reflects the positive influence of natural conditions on production efficiency.

For the evaluation indicators in terms of benefits, the most directly visible evaluation indicators are grain_export and agricultural GDP. From the point of view of the food security system, a sufficient and stable food supply is only a necessary but not sufficient condition for achieving food security. If the food is geographically distributed Uneven, and food-deficit areas are unable to purchase food (including material and economic capacity, which mainly refers to the lack of transportation infrastructure), it will inevitably produce regional food security problems. Therefore, the cost of transportation is also something we need to consider. At present, the food produced in the world is enough to meet the consumption of the global population, but there are still some people in the world who are still in a state of food insecurity, largely for this reason. However, due to the complexity of the transportation systems and food transportation processes in various countries, we have not been able to obtain specific data for this indicator. Therefore, in this study, we did not consider it and analyze it and will incorporate it into the subsequent sensitivity analysis.

In terms of fairness, in order to better reflect the internal fairness of a food system, we have included two important indicators, the hunger index GHI and the food Gini coefficient.

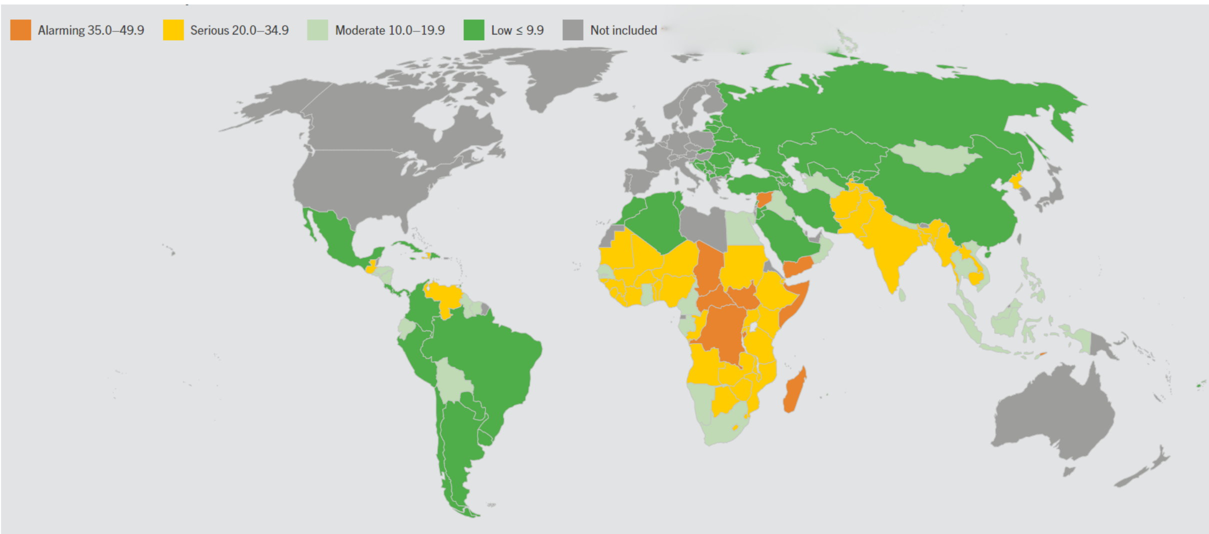


Figure 2: 2020 GLOBAL HUNGER INDEX

As a member of the Consultative Organization for International Agricultural Research, the International Food Policy Research Institute regards the achievement of the United Nations Sustainable Development Goals as an important task, is committed to seeking sustainable solutions to eradicate hunger and poverty, and publishes the Global Hunger Index (GHI) in October each year.). This indicator system includes four standardized indicators: the percentage of the undernourished population, the wasting rate of children under 5, the stunting rate of children under 5, and the mortality rate of children under 5. The four standardized indicators are combined into one index to reflect The multidimensionality of hunger. The index is between 0-100. The lower the score, the better the food security of a country. The calculation of the hunger index score uses a three-step process. First, determine the values of four standardized indicators for each country; second, according to the highest level of each indicator observed on a global scale in recent decades, each of the four indicators is standardized with 100 points Score; Third, give equal weight to each indicator, and calculate the hunger index for each country based on standardized scores. It can be seen that GHI fully considers the multiple indicators of food security and equity. According to various data from FAO and the World Bank, we have calculated and sorted out the GHI values of 23 major countries. For the default values, we cleaned and fitted them.

Gini coefficient is an indicator of the fairness of annual income distribution defined by the Italian scholar Corrado Gini in the early 20th century based on the Lorenz curve. It is a proportional value, between 0 and 1. When applied to the grain system model, it can better reflect the uniformity of grain distribution among people in different regions. The smaller the Gini coefficient, the more even the grain distribution and the better the fairness.

In terms of sustainability, according to relevant research and investigations, the impact of the food system on the environment is mainly reflected in the emission of greenhouse gases and the reduction of forest area due to farmland reclamation. Therefore, we include forest area in consideration of sustainability. Ratio and per capita greenhouse gas emissions.

3.2 Correlation Analysis

Before evaluating the evaluation criteria of the overall food system, we must first analyze the correlation of the analyzed variables. Find the correlation between different influencing factors through correlation analysis. Find those factors that may affect our evaluation model. In the specific calculation process, we use the Pearson correlation coefficient calculation.

The characteristic of Pearson's correlation coefficient is that changes in the position and scale of the two variables will not cause the coefficient to change

The Pearson correlation coefficient of two variables is defined as the covariance of the two variables divided by the product of their standard deviations:

$$\rho_{X,Y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E\left[(X-\mu_X)(Y-\mu_Y)\right]}{\sigma_X \sigma_Y}$$

By calculating the Pearson correlation coefficient between all the factors, we get the following correlation coefficient matrix

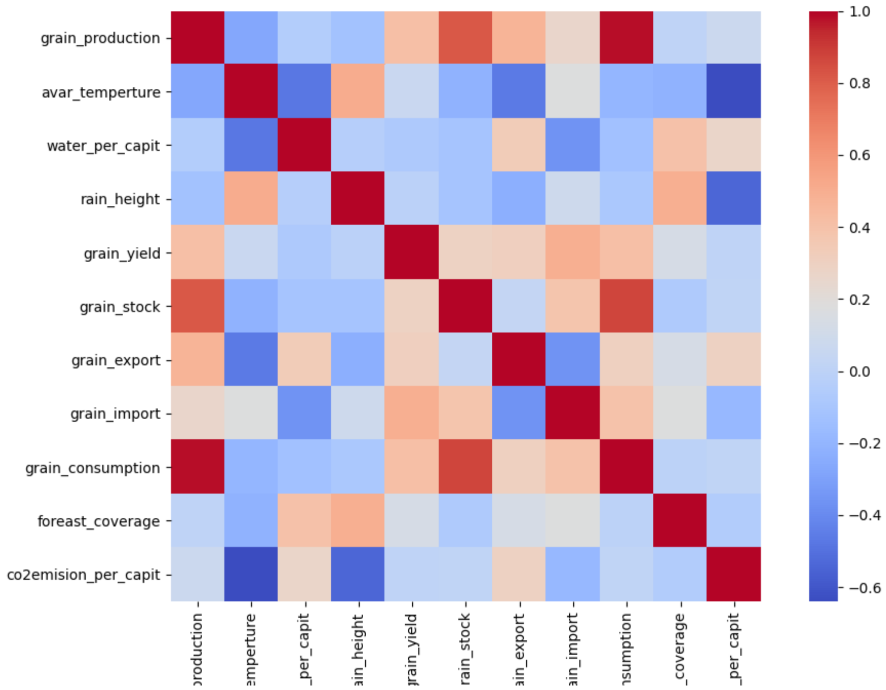


Figure 3: Correlation Matrix

We found from the figure above that :

1. Food production and food consumption have a high correlation. Food is at the lowest level of human survival needs. When people's basic needs for food are met, they often spend more time and energy in pursuing the enjoyment of other materials and services.

Therefore, food security issues are often overlooked. But once there is a problem with food security, its ripple effect is very obvious. Therefore, food produced by various countries is first used for domestic use.

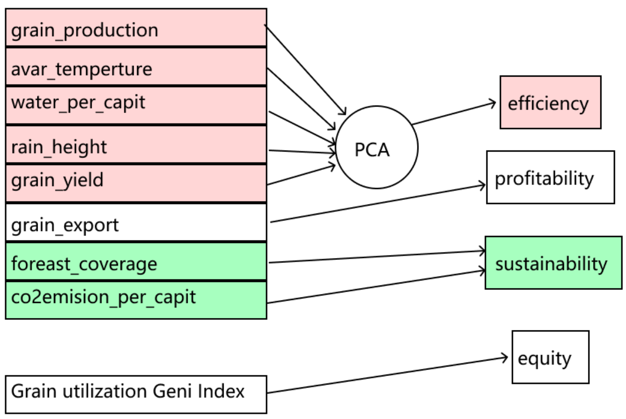
2. Increasing CO2 emissions will lead to global warming and more extreme weather, which will cause melting of snow in the Arctic and Antarctic, rising sea levels, frequent extreme droughts and floods, and inundation of coastal deltas. The CO2 produced by the burning of traditional fossil energy is the main cause of the greenhouse effect.

   From the above figure, it is found that there is a high negative correlation between per capita CO2 emissions and average temperature. This is because the countries with higher per capita CO2 emissions are mainly developed countries. Most of the developed countries are in high latitudes, where the average temperature is low.

3. Grain stock and food consumption have a high correlation. The greater the consumption of grain, the greater the amount of grain a country needs to store to ensure a stable supply of domestic grain. This is consistent with our usual common sense.

3.3 Efficiency Indicators Analysis Using PCA

In the process of evaluating the world food system, the evaluation indicators are divided into four aspects: efficiency, profitability, sustainability, and fairness.



3.3.1 National efficiency assessment

In the food system, efficiency factors are considered in order to evaluate the ability of various countries to grow crops under different natural conditions. We need to consider the differences in natural conditions between different countries. Therefore, two variables are obtained by principal component analysis (PCA) from the four factors of average temperature, per capita water resources, rainfall, and crop yield per mu. Evaluate a country's natural resource level through these two variables.

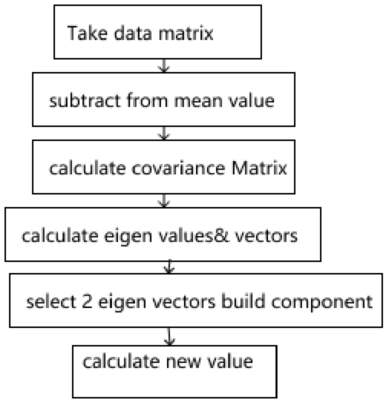


Figure 4: Flow Chart of PCA

So we got the two components of PCA

$$T_1 = a_1AT + a_2WPA + a_3RH + a_4GY$$

$$T_2 = b_1AT + b_2WPA + b_3RH + b_4GY$$

$$a_1 = -0.2207929 \quad b_1 = 0.51886374$$

$$a_2 = 0.97412436 \quad b_2 = 0.15605308$$

$$a_3 = -0.04460765 \quad b_3 = 0.84049003$$

$$a_4 = -0.01850342 \quad b_4 = -0.00208676$$

The data scatter chart obtained after the data is analyzed by principal components is as follows

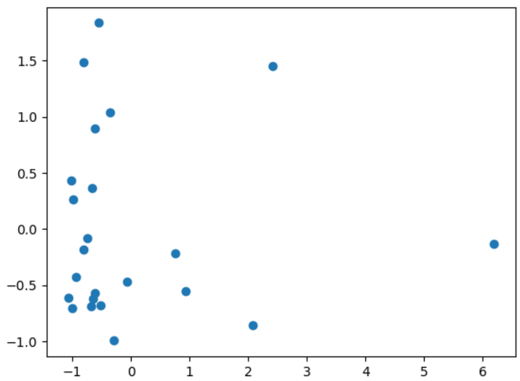


Figure 5: Scatter Plot of Factors after PCA

Among them, T1 component accounts for 73.01%, and T2 component accounts for 18.40%

3.3.2 Efficiency index of each country

$$EF = \frac{T1 + T2}{2}$$

We get the efficiency index of some countries

Countries	Efficiency Index Scores
Argentina	1.369985215
Australia	1.29012634
Canada	4.130862017
China	0.420050923
European Union	0.505902022
Nigeria	0.812030889
Saudi Arabia	0.259002153
Turkey	0.466720456
United States of America	0.835005814

Table 1: Efficiency index of some countries

Based on the above data, through analysis of the obtained index, Brazil has better natural conditions, sufficient water resources and arable land, and higher yield per mu than other countries. Canada has the highest per capita water resources in the world, and developed countries have high agricultural technology and have also received high efficiency ratings. However, Egypt has less water resources and lower yield per mu of arable land, resulting in a lower final score. Therefore, in the world, it is necessary to select regions suitable for agricultural development to develop agriculture in order to achieve higher efficiency.

3.3.3 Profitability and sustainability

We obtained data for the past 10 years through the World Bank database. From these data, we find that a countrys export volume can reflect the countrys influence on the international grain market and can measure a countrys profitability.

Sustainability is measured by a countrys carbon dioxide emissions and forest coverage to quantify a countrys green index to reflect a countrys sustainability index.

3.3.4 Equity

Although there is a lot of food production in the world, there are still many people who cannot get enough food nutrition. In our grain system, there are many links from grain production to sales. Through the analysis of the data, we found that there is a big difference in per capita food consumption between developed and developing countries. So we use the Gini coefficient of food utilization to measure the equity of the world's food system.

The Gini coefficient of food utilization is calculated by drawing the Lorentz curve to calculate the area ratio of the two parts of the Lorentz curve, so as to study the uneven distribution of national food in the world food system.

$$Geni = \frac{A}{A+B}$$

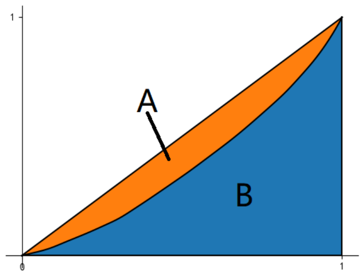


Figure 6: Lorentz Curve of Grain Utilization Per Capita

We've got that te Gini Coefficient of Per Capita Food Consumption is 0.2471

Although there is little difference in the actual food consumed by humans in different parts of the world, the dietary structure of developed and developing countries is quite different. The proportion of meat diet in developed countries is relatively large, while the production of meat Food requires a feed composed of grains, which has resulted in the per capita grain consumption in developed countries being much greater than that in low-income countries, where the difference between the highest value and the lowest value is about 8 times.

3.4 Establish a Comprehensive Evaluation Based on the Entropy Method

With the expansion of the connotation and extension of the concept of the food system, single indicators such as grain production can no longer fully reflect the food security situation, which makes the multi-indicator comprehensive evaluation method an effective tool for food system evaluation. This article follows the steps below to conduct a comprehensive multi-index evaluation of food security.

As pointed out earlier, our assessment of the quality of a food system is mainly considered from the four aspects of efficiency, profit, fairness and sustainability. Therefore, we have established a sub-evaluation system for these four aspects, namely, the efficiency of food production and supply, the profitability of the food system, and the internal fairness of the food system as the four secondary indicators, and the source data we obtained after cleaning as the third level The three-level indicators are classified under each of the second-level indicators to form a three-tiered bottom-up evaluation system for the food system.

First Grade Index	Second Grade Index	Third Grade Index	Index Tropism	Measurement Methods
	Food production and supply efficiency	X1:Grain yield per mu	+	ton
		X2:Inventory in the past five years	+	ton
		X3:Average export volume in the past 5 years	+	ton
		X4:Average annual output in the past 5 years	+	ton
Food System Evaluation Index	Profit of Food system	X5:Average export volume in the past 5 years	+	ton
		X6:Agricultural GDP	+	million dollar
	Internal equity of the food system	X7:Gini index	-	
		X8:global hunger index(GHI)	-	
	The sustainability of the food system	X9:Forest area ratio	+	m^3
		X10:C02 emision per capit	-	km^2

Table 2: Food System Evaluation Module

3.4.1 Determination of evaluation index weight

Index weight refers to the importance relationship of each index under the same objective constraints. In the comprehensive evaluation of multiple indicators, weight plays a pivotal role. We use the entropy coefficient method to assign weights to food security evaluation indicators. The main steps are as follows:

1. **Standardized data**
   Since the dimensions and magnitudes of the indicators and the positive and negative orientations of the indicators are different, the initial data needs to be standardized. For the positive and negative types of indicators, the standardization method is as follows:

   For positive indicators:

   $$X'_{ij} = (X_{ij} - \min X_j) \,/\, (\max X_j - \min X_j)$$

   For negative indicators:

   $$X'_{ij} = (\max X_j - X_{ij}) \,/\, (\max X_j - \min X_j)$$

2. **Calculate the weight of the i-th country in the j-th indicator value of all countries:**

$$Y_{ij} = X'_{ij} / \sum_{i=1}^{m} X'_{ij}$$

3. **Calculate index information entropy :**

$$e_j = -k \sum_{i=1}^{m} \left(Y_{ij} \times \ln Y_{ij}\right) \left(k = \frac{1}{\ln m}, 0 \leqslant e_j \leqslant 1\right)$$
$$Y_{ij} \times \ln Y_{ij} = 0 (Y_{ij} = 0)$$

4. **Calculate information entropy redundancy :** $d_j = 1 - e_j$

5. **Determine the index weight :** $w_i = d_j / \sum_{j=1}^{n} d_j$

3.4.2 Grain evaluation index and the synthesis of each sub-evaluation index

- We have got the entropy weight of each three-level index according to the above-mentioned standardization process and then calculated the entropy weight of each sub-evaluation system according to the corresponding relationship between the two-level index and the third-level index.

$$SubW_i = \sum_{j=1}^{n} w_i (i = 1, 2, 3, 4)$$

Get the entropy weight matrix $SW = [x_1, x_2, x_3, x_4]$
then we can calculate the score of each sub-evaluation index

$$h_i = \sum_{j=1}^{n} \left(X'_{ij} \cdot w_i\right) (i = 1, 2, 3, 4)$$

We use our collected data and find out the following entropy weight matrix

Sub-evaluation Index	Entropy Weight
Efficiency	0.569010377
Profitability	0.312208217
Sustainability	0.037501
Equity	0.081280407

Table 3: Entropy Weight without Interest Coefficient Matrix

- According to the relevant research, the interest coefficient matrix $R = [IH1, IH2, IH3, IH4]$ is established for the four indicators. For the parameters in the matrix, we take $IH_1 = 0.39$, $IH_2 = 0.54$, $IH_3 = 6.6728$, $IH_4 = 4.42$
The weight matrix after considering subjective evaluation is $W = SW \times R$
After that, normalize W to get W'

Sub-evaluation Index	Entropy Weight
Efficiency	0.221914047
Profitability	0.168592437
Sustainability	0.359259398
Equity	0.25023667

Table 4: Entropy Weight Considering Interest Coefficient Matrix

- Finally, with the weighted matrix, the four sub-indices are weighted to obtain the final score of each evaluation system.
- The following is the application of the evaluation model on typical developing countriy and developed country:

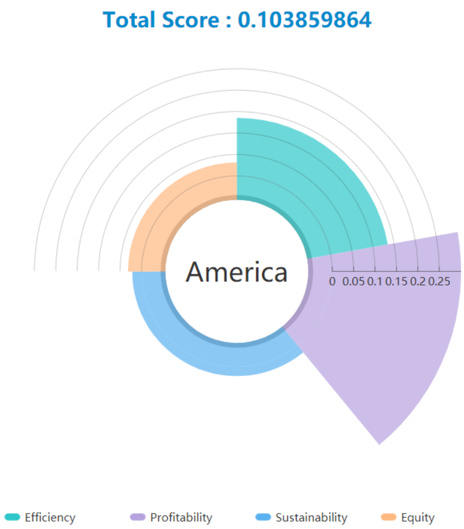


Figure 7: America

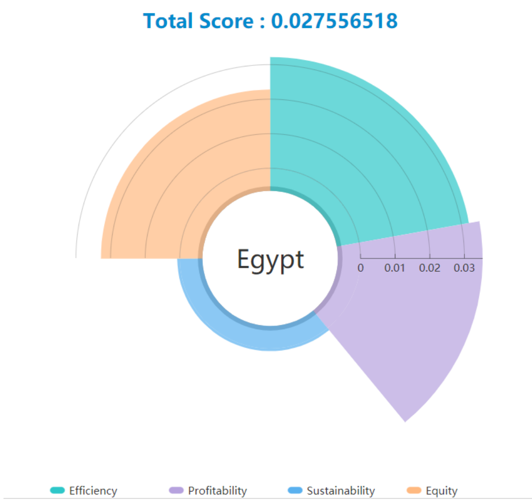


Figure 8: Egypt

- Considering the total score and sub-index scores of 23 major countries, we get the scores of the current world food system, as shown below

Sub-evaluation Index	Score
Efficiency	1.868346201
Profitability	1.579923528
Sustainability	0.591553737
Equity	0.96139793
total	5.001221396

Table 5: Scores of Current World Food System

4 Optimization of existing models

4.1 Model for optimizing trade network

4.1.1 Purpose

To optimize the equity of the existing food system, we can start from the food supply chain and food distribution. By building the food trade network, maximize the amount of food in the circulation of the trade network to realize the equity of the food system, which is as known as the maximum-flow problem. At the same time, to give attention to both efficiency and profitability and efficiency, we set the trade network's edges with weight and cost, seeking a minimum cost and maximum cost.

4.1.2 Assumption

To construct the trade network model, the following assumptions need to be noted:

1. Countries or regions need to meet their own food needs as far as possible before they trade in food.
2. It is assumed that when food is traded across borders, the overall price of food is similar and does not fluctuate much.
3. The loss of food in the course of trade is not taken into account.

4.1.3 Data processing

According to the World Trade Organization and UN Comtrade Database, we randomly select three countries or regions in high, upper-middle, lower-middle, and low income respectively. Defining food trade factors (food comprises the commodities in SITC sections 0 (food and live animals), 1 (beverages and tobacco), and 4 (animal and vegetable oils and fats) and SITC division 22 (oil seeds, oil nuts, and oil kernels)):

$$ftf_i = (MX_i \times FXP_i - MM_i \times FMP_i)/(MX_i \times FXP_i + MM_i \times FMP_i)$$

In the formula, MX_i represents the average merchandise trade exports value of a country or region from 2015 to 2019, FXP_i represents a country or region's average food exports proportion of its merchandise trade exports value from 2015 to 2019, while MM_i and FMP_i are representing the import value and food import proportion.

Figure 9: Food Trade Factor

The food trade factor ftf represents the role of a country or region in the international food trade network.

Based on the food trade factor, we set the countries of ftf as the sink point, which represents the food receiver, countries of $ftf \geq 0.25$ are set as source points, which represents the food suppliers. Then countries of $ftf \in (-0.25, 0.25)$ act as transfer countries which mainly responsible for the transport of grain or food.

Among them, some countries or regions because of some reasons such as war, food import, and export data are missing, In this regard, we label them as either source points (food suppliers) or sink points (food receivers) according to the value of their imports and exports and their income level, because such countries or regions are not suitable as a transfer due to wars or poverty.

If the country is an agricultural country, to promote its agricultural development, set it as a source pointe (food supplier), otherwise set it as a point of exchange (food receiver) to supply its food needs, due to its low income or state of war.

So, we got three categories of countries or regions, and we labeled them on the map of the world:

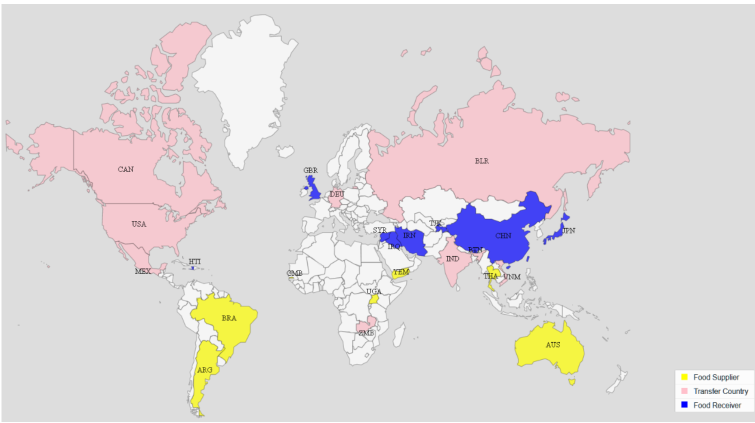


Figure 10: The Role in the Food Trade Network Labeled in the World Map

As is shown in the map, the yellow areas are food suppliers, the pink areas are transfer countries, and the blue areas are food receiver.

4.1.4 Food Trade Network

Considering the scope of food trade, we selected some major food trading partners based on the data from the UN Comtrade Database, and to give priority to equity, we established the following food trade network diagram.

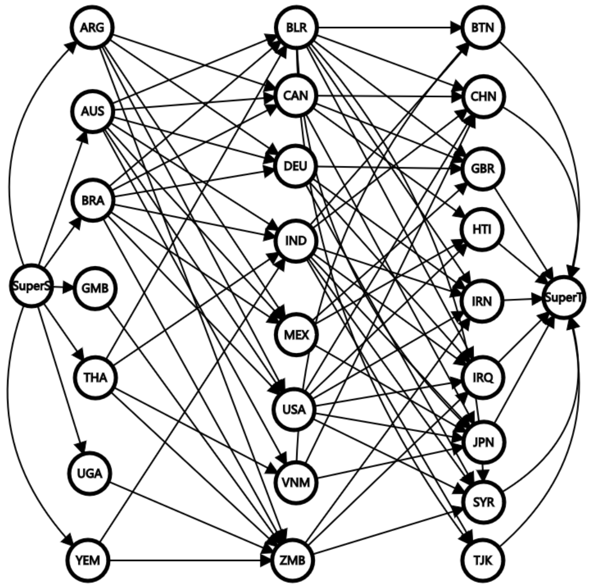


Figure 11: Food Trade Network

The weight $w(u, v)$, where $u, v \in E$, of the trade network's edge, is essentially a capacity, which means the maximum grain exports.

For each food supplier, the sum of its capacity to the grain transfer station is its grain export value.

For each food transfer country, the sum of its capacity to the food receiver is the amount of its food export value and the number of food imports provided by its suppliers.

The weight of these edges is determined by the proportion and trade value of food trade between the two countries or regions (current price USD $).

This is not a complex network. The real global food trade network is much more complex.

Among them, SuperS and SuperT on the left and right of the figure are super source points and super sink points respectively. This can be understood as a food warehouse, from which the supplier obtains food and the receiver stores food, so its edge weight is infinity. Its main purpose is to implement the maximum flow algorithm, which is generally not of practical significance.

4.1.5 Maximum flow problem

We treat the food trade network as a directed graph and as a flow network. To solve the problem of food supply and distribution, imagining that food passes from a food supplier (source point) to a food receiver (sink point) through several transfer stations, with the source point producing food at a steady rate and the sink point consuming food at the same rate.

We use the maximum flow algorithm to solve the food distribution problem, where we want to calculate the maximum rate at which food can be transported from the source point to the sink point without violating any capacity constraints.

4.1.6 Definition

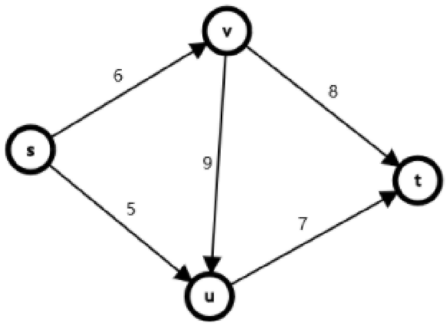


Figure 12: Maximum flow problem

- **Source:** food supplier countries that only export food in the food trade network
- **Sink:** food receiving country that only imports food in the food trading network
- **Transfer:** transfer countries in which only food is transported in the food trading network.
- **Flow:** The amount of food being carried along an edge
- **Capacity:** The maximum amount of flow that can flow over an edge
- **Residual:** *capacity* - *flow* on one edge

4.1.7 Basic properties

Basic property one: for any edge, there is always $flow \leq capacity$

Basic property two: for any node u in food trade network E that is not a source or a sink, it always has the property:

$$\sum_{p \in E} k\left(p, u\right) \equiv \sum_{q \in E} k\left(u, q\right), \ where\ k(u, q)\ means\ the\ flow\ from\ node\ u\ to\ v$$

Basic property three: for any directed edge (u, v), it always has the property $k(u, v) \equiv -k(v, u)$

4.1.8 Algorithms

Most algorithms for network flow are based on the Augmented Path Theorem (a network reaches maximum flow if and only if there are no augmented paths in a residual network), and the main principles of finding maximum flow are: as long as there is a path from the source (start node) to the sink (end node), with available capacity on all edges in the path, we send flow along with one of the paths. Then we find another path, and so on. A path with available capacity is called an **augmenting path**.

In the food trade network, because there are many edges in the network, we use the *Dinic* algorithm which has a better time complexity of dense graphs.

The general process of Dinic algorithm is as follows:

Let $G = ((V, E), c, s, t)$ be a network with $c(u, v)$ and $f(u, v)$ the capacity and the flow of the edge (u, v), respectively.

The **residual capacity** is a mapping $c_f : V \times V \to R^+$ defined as

- If $(u, v) \in E$, then $c_f(u, v) = c(u, v) - f(u, v)$
- $c_f(u, v) = 0$ otherwise

The residual graph is an unweighted graph $G_f = \left((V, E_f), c_f|_{E_f}, s, t\right)$, where $E_f = \{(u, v) \in V \times V : c_f(u, v) > 0\}$.

An **augmented path** is an $s - t$ path in the residual graph G_f.

Define $dist(v)$ to be the length of the shortest path from s to v in G_f. Then the level graph of G_f is the graph $G_L = ((V, E_L), c_f|E_L, s, t)$, where $E_L = \{(u, v) \in E_f : dist(v) = dist(u)+1\}$

A blocking flow is an $s - t$ flow f such that the graph $G' = ((V, E_L'), s, t) with E'_L = (u, v) : f(u, v) < c_{f|_{E_L}}(u, v)$ contains no $s - t$ path

Input: A network $G = ((V, E), c, s, t)$.

Output: An $s - t$ flow f of maximum value.

- Set $f(e) = 0$ for each $e \in E$.
- Construct G_L from G_f of G. if $dist(t) = \infty$, stop and output f.
- Find a blocking flow f' in G_L.
- Add augment flow f by f' and go back to step 2.

4.1.9 Minimum cost and maximum flow problem

The minimum cost and maximum flow are based on the maximum flow and network flow problems. Directed graph with weights $G = ((V, E), f, w, s, t)$ is a special flow network, which every edge $(u, v) \in E$ including $c(u, v) \in R^+$ is called capacity, while $w(u, v) \in R$ is called $cost$, the minimum $\sum (f(u, v) \times w(u, v))$ is the minimum cost and maximum flow.

While the maximum flow means the largest amount of the food flowing in the food trade system, we can also add another weight on the edge of every two nodes, to indicate the transportation cost between the two countries or regions. According to the total food import and export trade of each country or region multiplied by a coefficient, we use its reciprocal to show that the countrys trade amount in the proportion of the total food trade network. The sum of two countries or regions of deg represents the trade cost of countries or regions. We use deg to represent the cost of trade between two countries or regions.

$$deg_i = \frac{1}{k \times (MX_i \times F\ X\ P_i + MM_i \times F\ M\ P_i)}$$

$$cost_i = deg_u + deg_v\ (u, v \in E)$$

To get the minimum cost of the maximum amount of food in circulation in the food trade network. Since there will be a negative weight when solving the minimum cost and maximum flow, we can use the SPFA (Shortest Path Algorithm) Algorithm of the Bellman-Ford Algorithm to realize it.

We use the queue data structure to implement the algorithm. The general idea is to use a queue for maintenance. Initially, we enqueue the source. Each time dequeue an element from the queue and relax all the nodes adjacent to it. If an adjacent node relaxed successfully, enqueue the node. While the queue is empty, the result is the minimum cost that we need.

What is interesting is that we can take the cost by its additive inverse, and take the minimum-cost also by its additive inverse. Then the result is the maximum cost. We can get interesting results when we compare the maximum cost to the minimum cost.

4.1.10 Results and Conclusion

In general, the purpose of classifying countries or regions and establishing the food trade network is to find the maximum amount of food supply in the network. Each country or region must try its best to meet its food demand first, then we divide them into suppliers, transfer, and receivers to achieve more efficient and equitable distribution, reduce food waste, and satisfying the food demand of as many countries or regions as possible.

By using the maximum flow problem, we get the maximum amount of food supply in the network is 79% of the total amount of the current food trade amount, the result tells us that the construction of food trade networks and the use of maximum flow algorithm to reoptimize the food system for more equity, the food trade amount is about 79% of the past, this greatly reduces the waste of food, transferring food as much as possible to countries in need.

Besides, we also construct the minimum cost maximum flow problem. To achieve the largest amount of food and equity, which may sound like a huge and expensive project, but in our model, by getting the minimum cost and maximum cost. We found that the minimum cost is only 53% of the maximum cost, this suggests that to realize the equitable food system, using the same food trade networks the additional cost is not that huge. With future development, we believe that the cost will decrease significantly by improving the agricultural facilities and technology in low-income countries and reduce the cost of food trading.

4.2 Agricultural Technology Optimization

In addition to differences in natural resource conditions, agricultural conditions in various regions of the world also have differences in agricultural technology. If we can enable backward countries to obtain advanced agricultural technology, agricultural productivity can gradually increase. If the acceleration of the agricultural growth rate can increase by 0.2% per year, the changes in future agricultural production for the following four countries are as follows.

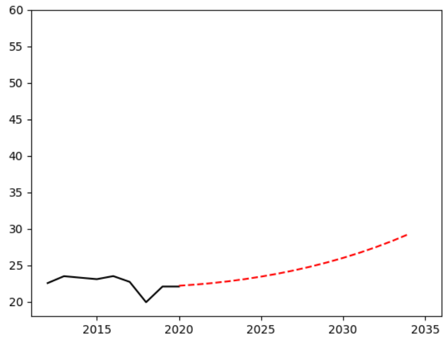


Figure 13: Egypt

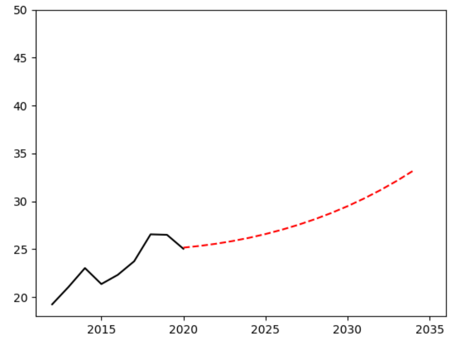


Figure 14: Nigeria

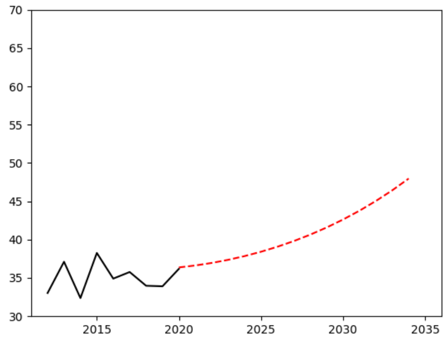


Figure 15: Turkey

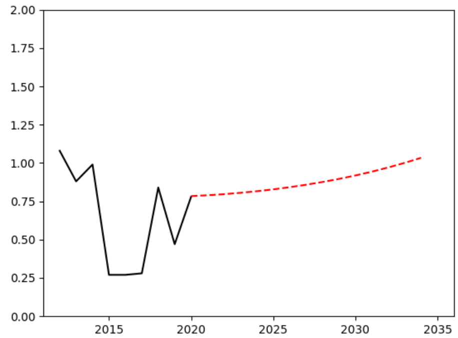


Figure 16: Saudi

Analysis: By improving agricultural technology, the total food production of these four countries can be increased to 99 million tons in 10 years, which is 3.6% higher than the current grain production.

This method requires a certain amount of learning costs, including the need to provide the equipment needed for agriculture and the establishment of a sustainable agricultural industrialization system, which is difficult to achieve for extremely poor countries.

If this method can be carried out effectively, it can better meet development needs in the long run. The development of technology often follows an exponential rule. Although it has limited short-term effects, the long-term benefits obtained by persisting in the long-term application of the method are very considerable.

4.3 Agriculture Alliance Optimization

In order to solve the problem of excessive differences in food production and distribution between different countries, and to improve the fairness and sustainability of the world's food system, we have decided to allow some countries to form groups. Several countries form a common agricultural consortium in agricultural cooperation, and share agricultural technology in the agricultural production link, which has increased the growth rate of food production. In the storage of grain, the joint storage of food can reduce the total storage capacity. According to the survey, due to the current storage conditions, the food stored in the granary will cause an average of 10% waste every year. For this, we selected Egypt, Nigeria, Turkey, and Saudi Arabia to form an agricultural community.

How to distribute food reasonably in an agricultural community is a problem. In the long-term cooperative benefit distribution game, there have been many ways to solve the distribution. Here we choose the Shapley value to solve the distribution problem within the agricultural complex.

The contribution of cooperation income is calculated by Shapley value method. The Shapley value method is a multi-player cooperative game benefit distribution method, which is generally applicable to problems related to the reasonable distribution of multi-party combined benefits, which means that one's own income and contribution are equal. It takes into account the marginal contributions of alliance members, and satisfies the uniqueness conditions of individual rationality, alliance rationality, fair efficiency, and distribution results. It is widely used in the research on the income distribution of different alliances.

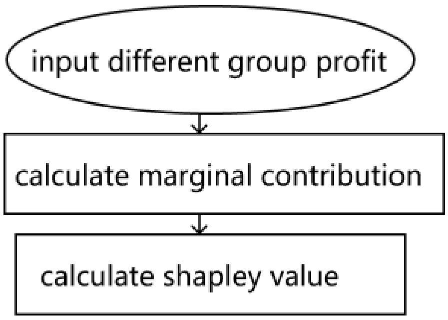


Figure 17: Flow Chart of Shapley Value Calculating

marginal contribution is the contribution of the i-th country joining the organization

$$\delta_i(S) = v(S \cup \{i\}) - v(S)$$

The corresponding shapley value calculation method is:

$$Shapley(S,i)/\varphi_i = \sum_{r \in R} \delta_i(S_i(r))/|n|!$$

The distribution coefficient between these four countries is calculated as:

Countries	Distribution Coefficient
Egypt	0.2650
Nigeria	0.3184
Turkey	0.4001
Saudi Arabia	0.0163

Table 6: The distribution coefficient between four countries

At the same time, the rest of the cooperation has brought about a longer-term increase in food production. According to calculations, if the growth of food production is equal to the growth rate of the fastest growing countries in the regional consortium, the change in food production is shown in the figure.

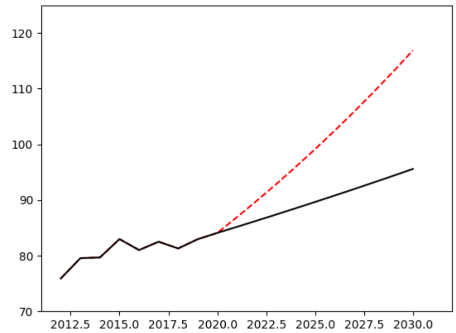


Figure 18: Agricultural Union Grain Production

Analysis:

Through regional cooperation, 10 years later, the total food production has increased to 116.87 millon tons, a growth rate of 22%.

At the same time, too much stored food will lead to more food waste, but through inter-regional cooperation to store food can make the supply of food more stable, cooperative storage of food can reduce the waste of stored food, through inter-regional cooperation, will The proportion of stored grain is reduced from 20% to 10%, which can reduce food waste by 2.3 millon ton and 0.57 millon ton of carbon dioxide emissions per year. Increase the sustainability score of these countries by 2.03%

5 Forecast model for long- and short-term impact

In order to predict the cost of changing our food system, we divide the costs and benefits into short-term and long-term.

For the short-term impact, the policy stability of the National Agricultural Union is also a test of this cooperation model. How to use the shortest possible time to build the necessary infrastructure in the agricultural complex, and how to share the cost are problems that need to be solved urgently. It will continue to be resolved over time. After optimizing the trade network, the profitability of agricultural products exporters decreased. The decline in profitability has led to an increase in the planting area of cash crops with relatively high economic benefits, leading to a decrease in the area of grain production and the simplification of crop products. But at the same time, after the area of food production is reduced, more land can be restored to the ecology and the sustainable development index can be improved. At the same time, because agricultural countries can also obtain food at a reasonable price, the fairness of the entire food system is improved.

For the long-term impact, after long-term development, the output of grain has increased substantially, but the increase in per capita grain demand is not significant. The world population capacity will gradually increase. Therefore, the short-term impact on food exporting countries is affected. In the next few decades, it is more important to make rational use of food. This requires countries and the world to pay attention to and guide consumers to choose more suitable food processing products from a policy perspective. At the same time, the ability of poor farmers to participate in agricultural production is guided, thereby reducing the Gini coefficient of per capita food utilization and improving the fairness of the world food system.

Use Autoregressive moving average model to predict future food production

$$X_t = c + \varepsilon_t + \sum_{i=1}^{p} \varphi_i X_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j}$$

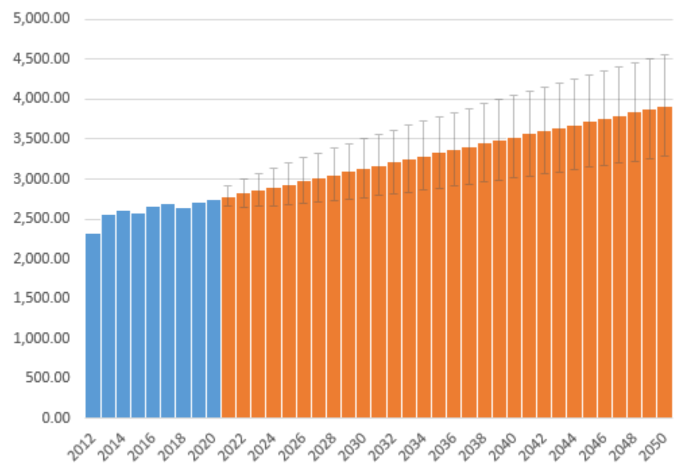


Figure 19: Forecast of world food production in 2050

According to population demand estimates, food production can meet the needs of 21.5 billion people, according to UN population estimates. The population at that time grew to approximately 9.7 billion. If we can make full use of the food produced, reduce waste as much as possible. We can reduce the low-yield arable land by half, save more water resources, and plant more forests. The sustainability index will be further improved. At the same time, due to the increase in the degree of world development, crop importing countries whose profits are affected in the short term. As the worlds population increases and has a larger market, these countries that are affected in the short term can make up for losses in the future by exporting more other consumer goods. In fact, this is an improvement in efficiency and profitability.

6 Analysis of Scalability and Adaptability

The establishment of our food system assessment model is based on the abstract concept of "region". As long as relevant data can be obtained, on only the food system of the state, but also the country or region or even the world can be evaluated by our assessment model. Our prediction model based on the existing assessment model will also has good adaptability.

For the existing food system, we construct the food trade network, using the maximum-flow and minimum-cost and maximum-flow algorithms to optimize for equity. Since our network model takes into account not only countries or regions with high, upper middle, lower middle and low income, but also the value of their food imports and exports, this model can well cope with the large-scale global food trade network. When the food trade narrows down to a continent among several countries or regions, even a country or a region among a few provinces, because they all need to satisfy their own demand for food, then consider the import and export of food (including across provinces trading), which can be done by building a network optimizing for equity. In general, our model has a good scalability and adaptability.

7 Strengths and Weaknesses

7.1 Strengths

Models can be widely used, not only for evaluating food systems, but also for evaluating other items with production, consumption and storage behaviors

Our model uses many theories and methods, which can be well explained.

7.2 Weaknesses

We have obtained a lot of data. Due to the large amount, we can only choose to evaluate some of them.

The result of the model largely depends on the accuracy of the forecast. Therefore, if there are major changes in the world structure in the future, the results may not be very reliable.

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