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Although the current global food system is highly efficient, there are many problems that cannot be ignored, such as the huge environmental impact caused by the priority given to benefits and profits, and the huge number of global hungry people caused by the inequity of the existing food system. In this case, a comprehensive optimization of the food system is needed.

We design **a multi-objective nonlinear optimization model** to optimize the industrial structure on the supply side. It will complete the adjustment of agricultural production structure according to the priority of profit, yield, balance index and environmental friendliness. By adjusting the proportion of grain cultivation and the number of livestock breeding, the highest priority of economic benefits, production benefits, equality benefits and environmental benefits will be maximized. Through the substitution of productivity, agricultural output and other values of different countries, the paper studies and analyzes the different performances of the agricultural production model that gives priority to the balance and sustainability of development and gives priority to the development of profit and yield in developed and developing countries.

We use **the improved grey prediction model with time delay**, find the best time delay coefficient by particle swarm optimization, and use the dynamic inertia weight of differential drop, dynamic learning factor and the idea of simulated annealing to optimize the particle swarm, greatly improve the convergence and local optimal solution problem. Combined with reasonable data assumptions and known data, we can predict the change of indicators in China and the United States in the next few years, and then predict the implementation time of the policy transformation for equitable and sustainable development in both countries.

We analyzed the differences between food models. Using **fuzzy comprehensive analysis method**, established a evaluation model of 21 indicators. The food model was comprehensively scored from four dimensions of sustainability, equity, economic profit and system efficiency. When food systems prioritize sustainability and equity, their economic profit scores fall, with a much larger drop (over 30%) in developing countries than in developed ones. That is consistent with the actual situation of now, pay attention to environmental protection will inevitably lose some profit, so the food system optimization is a need to consider the long-term process.

Finally, the scalability and adaptability of the model are analyzed, and the sensitivity of the DSPTDGM prediction model and the supply-side structure optimization model is analyzed to verify its stability.

Keywords: Food System; Supply side; Multi-objective nonlinear optimization model; Time-delay grey prediction; Fuzzy evaluation; Sustainability

Contents

1 Introduction

1.1 Introduce the background

The globalization of the modern agricultural food system is closely related to the global food trade since it entered the stage of post-productionism. The strengthening of the global food relationship continues to disintegrate the previous food relationship based on countries and regions, leading to the rupture of the relationship between food, origin and consumption [1]. The agri-food system has periodically been under the pressure of transformation in the past few decades and has been responding to difficulties and crises through structural adjustment. There was a lock-in effect, and productionism brought the illusion of surplus, which made food security to be issued for a long time. The industrialized production mode widely practiced during this period changed the quality of food and became a potential threat to food security. The strengthening of global food trade in the post-productivist stage leads to the privatization and marketization of food security, and weakens the fairness and public nature of the supply system.

1.2 Problems we faced

At present, the food system presents complexity. On the one hand, agricultural modernization, agricultural industrialization, agricultural science and technology innovation, global agricultural trade and so on have become the mainstream policy orientation and social consensus; But on the other hand, the current system of food produced many social and environmental issues related to agriculture and food, such as hunger due to unfair distribution system of food, a condition in which the ecological environment is severely damaged in the course of agricultural production, the loss of impartiality and public which supply system suffer and a series of serious problems.

One of the most prominent problem is hunger. The current global food production can meet the needs of the world's population, and hunger has been declining gradually worldwide since 2000, but in many countries and regions, the speed of agricultural development is slow and the level of industrialization is low, and hunger is still serious. In addition, These places are highly vulnerable to the exacerbation of food and nutritional insecurity caused by the overlapping health, economic and environmental crises. By reviewing the relevant data, we have produced the 2020 Global Hunger Index (GHI) chart, broken down by severity.

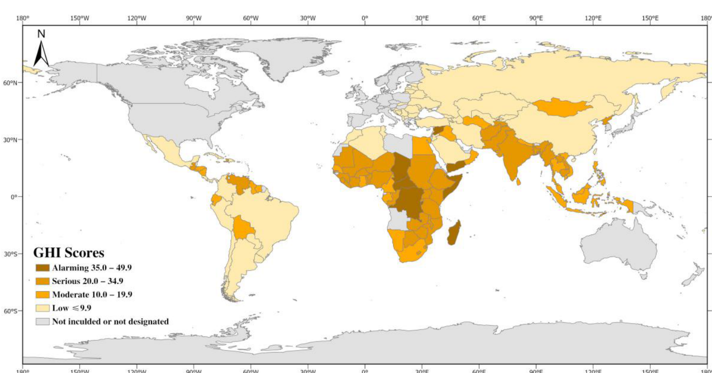

Figure 1: 2020 Global hunger index by severity

The current food system causes enormous environmental impacts, accounting for 29 percent of greenhouse gas emissions, up to 80 percent of biodiversity loss, 80 percent of deforestation, and 70 percent of freshwater use. Without targeted mitigation measures, current and projected agricultural practices will greatly affect the planet's environment.

Due to anticipated socio-economic developments, food production and consumption are expected to change between 2020 and 2050. These developments include global population growth of about a quarter (range 21-27%, from 7.6 billion in 2020 to 8.5 -10 billion in 2050), and a doubling of global income (range 1.8-2.3, from $87.75 trillion in 2020 to $157.95- $201.82 trillion in 2050).

By referring to relevant literature [2], due to these changes, we predict that in the absence of technological change and other mitigation measures, the environmental pressure on the food system of each index will increase by 16-62%, which is a huge environmental pressure. The projected further impact of the current food system on five environmental areas by 2050 relative to 2020 is as follows, the biggest growth for greenhouse gas emissions (43%, 38-62%), and then the demand for land use (36%, 32-37%), the use of water (34%, 31-35%), and phosphorus application (19%, 16-23%), nitrogen application (21%, 18 -22%).

Tables of the impact of different food groups on five environmental areas of environmental stress by 2020 and 2050 are drawn. As shown in figure2 (source of data):

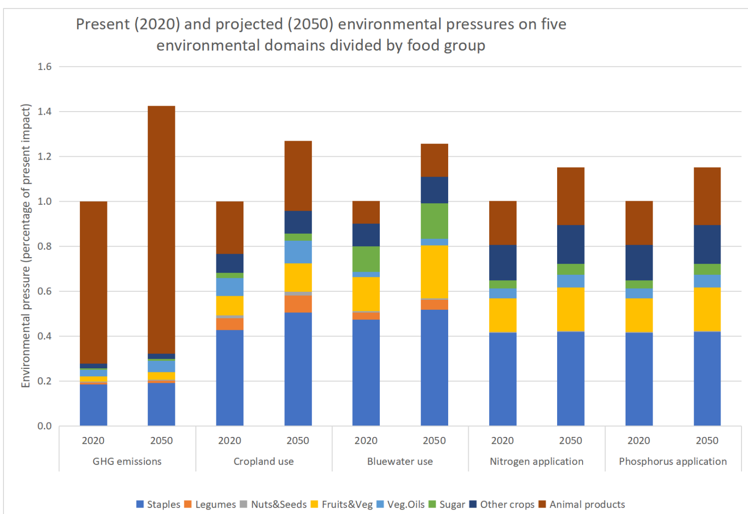

Figure 2: Present(2020) and projected(2050) environmental pressures on five enviromental domains divided by food group

As shown in the figure, the environmental impact of a given food group varies. Animal products produce most greenhouse gas emissions associated with food production (72-78% of the total emissions of agriculture), this is due to the low feed conversion efficiency, the intestinal fermentation of ruminants and emissions associated with manure, the influence of animal products related to feed also caused the groundwater usage (about 10%) and the pressure of crops, as well as the application of nitrogen and phosphorus (18-22%). The environmental impact of major crops is usually lower than that of animals, especially greenhouse gas emissions, but their total impact can be high due to the high crop yields.

It is estimated by reference that the major crops grown for human consumption account for between a third and a half of arable land use, groundwater use, and nitrogen and phosphorus use [2]. Projected population growth between 2020 and 2050 contributes to a general increase in the impact of each food group. Projected income growth changes the relative contribution of each food group, with animal products, fruits and vegetables having a larger impact and staple crops having a smaller impact.

1.3 What should we do

By analyzing the current problems faced by the food system, we should pay more attention to the impact of the food system on the environment, pay more attention to sustainable development, pay more attention to fairness in food distribution, reduce the global hungry population as much as possible, and reduce the waste of food when establishing a new food system. At the same time, on the basis of the original food system, and on the premise of not destroying the environment and ecology, the efficiency should be improved as much as possible to produce more food. Based on this, we built a new food system model to achieve these goals.

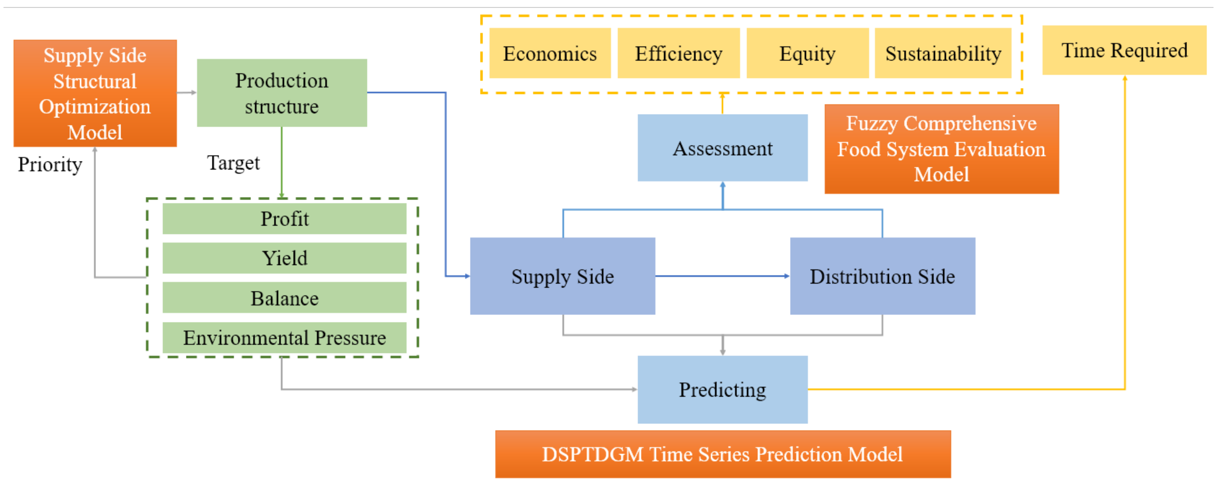

Figure 3: General block diagram of the model

2 Modeling

2.1 A new food system model

2.1.1 Assumptions

- The total area of arable land occupied by all food crops remains unchanged
- Food prices are stable

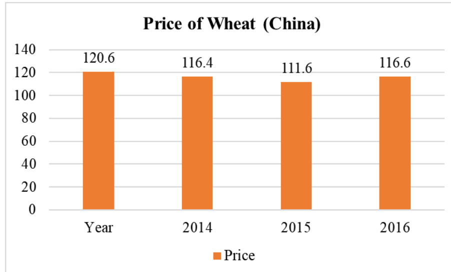

Figure 4: Wheat prices barely budged

- Food production is stable
- The proportion of dry land, irrigated land and paddy land in arable land remained unchanged
- The following 7 kinds of crops and 4 kinds of livestock are selected as the main production products and the introduction of new categories of crops and livestock is not considered

Food crops	Wheat, sorghum, barley, rice, soybeans, corn, potatoes
meat	Beef cattle, lamb, pig, chicken

- The same Labour force can be used to grow food crops and raise livestock at the same time without conflict[10]

Figure 5: The input of labor in a day

- The distribution of agricultural population is relatively uniform, can be regarded as the agricultural population of each unit of arable land area is equal

2.1.2 Notations

Symbols	Meanings	Unit
P(x)	The porfit benefits that can be obtained under the structure X	U.S. Dollar
F(x)	Food yield under the structure X	Kg
E(x)	The index of social sources balance caused by structure X	-
C(x)	The pressure on the environment under the structure X	-

Xrepresents the components and proportions of the entire supply structure. The meanings and symbols are shown in the table below. The component number of $X$is described as $J.x_1 3\ x_J$, which is the import/export component and can be adjusted dynamically according to the regional situation.

Wheats	Sorghum	Barley	Rice	Soybean	Corn	Cattle	Sheep	Pig	Chicken	Potato	Uncultivated land
X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_10	X_11	X_12

2.1.3 Factors affecting the model

all factors:

The objective factors of the region	The objective attributes of various foods	Other Variables
Regional total arable area	Yield Per Unit	Food needs
Regional total population	Profit Per Unit	Intensification Level
Regional total agricultural population	Labor Per Unit	Balanced Dietary Factors
Regional grain production proportion	Environmental Pressure Per Unit	Import / Export Restriction Factors (IERF)
Regional irrigation level proportion		

Environmental Pressure Per Unit:

	GHG emissions	Cropland use	Bluewater use	Nitrogen application	Phosphorus application
Staples	0.1851	0.4271	0.4741	0.414	0.414
Legumes	0.0079	0.0527	0.031	0.001	0.001
Nuts&Seeds	0.0048	0.0135	0.007	0.0032	0.0032
Other crops	0.0217	0.0858	0.1006	0.1581	0.1581
Animal products	0.7226	0.2335	0.1004	0.1953	0.1953

Balanced Dietary Factors:

	Mediterranean	the East	the West
Legumes (g/d)	30	11	1
Cereals (g/d)	453	440	123
Potatoes (g/d)	170	86.6	124
Red meat & poultry (g/d)	35	89.5	273

2.1.4 Constraints on the model

all constraints:

Labor constraint	Social minimum demand constraints
Restrictions on livestock and poultry roughage	Grazing constraints
Balanced dietary requirements constraints	Intensification degree constraint
Irrigation degree constraint	Non-negative constraints

Social minimum demand constraints[9]:

Wheats	Sorghum	Barley	Rice	Soybean	Corn	Potato
0.818	0.85	0.85	0.85	0.199	0.107	0.818

2.1.5 Create Model

The objective functions and constraints:

$$D[Z(x), Z^0] = [\sum_{i=1}^{r} w_i(Z_i(x) - Z_i{}^*)^2]^{1/2}, minP(x) = \sum_{i=1}^{j} PPU_i * y_i$$

$$minY(x) = \sum_{i=1}^{j} YPU_i * y_i, minC(x) = \sum_{i=1}^{j} EPPU_i * y_i$$

$$minE(x) = \sum_{k=Mean|Grain} Wasted_k = \begin{cases} NF_k - Product_k, Product_k < NF_k \\ (-NF_k + Product_k) * Wasted\_rate, Product_k \geq NF_k \end{cases}$$

$$\begin{cases}
X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_{11} + X_{12} = 1 \\
0.03 * X_7 + 0.0006 * X_8 - X_{12} \leq 0 \\
LPU_1 * X_1 + LPU_2 * X_2 + LPU_3 * X_3 + LPU_4 * X_4 + LPU_5 * X_5 + LPU_6 * X_6 + LPU_{11} * X_{11} \leq \frac{RAP*180}{RAA} \\
LPU_7 * X_7 + LPU_8 * X_8 + LPU_9 * X_9 + LPU_{10} * X_{10} \leq \frac{RAP*180}{RAA} \\
YPU_7 * X_7 + YPU_8 * X_8 + YPU_9 * X_9 + YPU_{10} * X_{10} + \alpha \leq -\frac{RTP*FN_{Meat}}{RAA} \\
-59.01 * X_5 - 199.91 * X_6 + 60.38 * X_7 - 11.19 * X_{12} \leq 0 \\
-989.54 * X_5 - 780.50 * X_6 + 500 * X_7 - 59.04 * X_{12} \leq 0 \\
-56.99 * X_5 - 172.27 * X_6 + 5.18 * X_8 - 19.46 * X_{12} \leq 0 \\
-216 * X_5 - 570.2 * X_6 + 48 * X_8 - 733.37 * X_{12} \leq 0 \\
-11.67 * X_2 - 15.7 * X_5 - 102.5 * X_6 + 6.14 * X_9 \leq 0 \\
-95.56 * X_2 - 61.65 * X_5 - 261.21 * X_6 + 62.10 * X_9 \leq 0 \\
-94.32 * X_6 + 0.51 * X_{10} \leq 0 \\
-261.21 * X_6 + 6.79 * X_{10} \leq 0 \\
X_4 \leq RIL \\
-YPU_1 * 0.818 * X_1 - YPU_2 * 0.85 * X_2 - YPU_3 * 0.85 * X_3 - YPU_4 * 0.85 * X_4 - 0.199 * YPU_5 * X_5 - 0.107 * YPU_6 * X_6 + 430.57 * X_7 + 48.79 * X_8 + 216.98 * X_9 + 6.06 * X_{10} - YPU_{11} * X_{11} \leq -\frac{RTP*FN_{Grain}}{RAA} \\
-X_1 \leq -Area_{old1} * \frac{(1-IL)}{RPG} \\
-X_2 \leq -Area_{old2} * \frac{(1-IL)}{RPG} \\
-X_3 \leq -Area_{old3} * \frac{(1-IL)}{RPG} \\
-X_4 \leq -Area_{old4} * \frac{(1-IL)}{RPG} \\
-X_5 \leq -Area_{old5} * \frac{(1-IL)}{RPG} \\
-X_6 \leq -Area_{old6} * \frac{(1-IL)}{RPG} \\
-X_{11} \leq -Area_{old11} * \frac{(1-IL)}{RPG} \\
IftheBLDisgreaterthan0, thereare: \\
-YPU_1 * 0.818 * X_1 - YPU_3 * 0.85 * X_3 - YPU_4 * 0.85 * X_4 + \alpha \leq -RTP/area * Recommendedcerealintake * 0.6 * BLD \\
-YPU_2 * 0.85 * X_2 - 0.107 * YPU_5 * X_5 + \alpha \leq -RTP/area * Recommendedcerealintake * 0.4 * BLD \\
0.199 * -YPU_5 * X_5 + \alpha \leq -RTP/area * Recommendedintakeofbeans * BLD \\
-YPU_{11} * X_6 + \alpha \leq -RTP/area * Recommendedintakeofpotato * BLD \\
-X_i \leq 0
\end{cases}$$

Figure 6: The set of constraint inequalities[8]

2.2 Evaluation Model:

In order to construct the food system evaluation system effectively, based on reading the relevant literature, four elements, namely sustainable development index, equity, economic benefit and system efficiency, were preliminarily determined. The primary indicators are screened and the evaluation indexes that are close to the actual food system are selected according to the current situation of industrial development. After comprehensive consideration, the comprehensive evaluation index system of food system was finally constructed, including 1 system layer, 4 element layer and 21 index layer.

Multi-attribute normalization is adopted for the indicators in the evaluation system, such as the ecosystem service value index in the system layer of sustainable development. Since this value is positively correlated with sustainable development, it is a revenue variable. For example, the proportion of food waste in the system layer of fairness is a cost variable because the increase of this value is not conducive to maintaining the fairness of the food system.

According to the actual situation, the 21 index layers were divided into cost variables and revenue variables to establish index matrix A, and I1 and I2 were used to represent benefit and cost indexes respectively. Thus, the benefit matrix or cost matrix B was established. In other words, each element of the matrix was transformed into benefit or cost indexes through dimensionless processing.

The model construction process is as follows:

$$B = (b_{ij})_{mn}$$

$$b_{ij} = \begin{cases} \frac{\alpha_{ij} - min\alpha_{ij}}{max_j\alpha_{ij} - min_j\alpha_{ij}}, \alpha_{ij} \in I_1 \\ \frac{min\alpha_{ij} - \alpha_{ij}}{max_j\alpha_{ij} - min_j\alpha_{ij}}, \alpha_{ij} \in I_2 \end{cases}$$

a_{ij} is the appropriate value of the jth index in the ith scheme.

b_{ij} is the result after dimensionless treatment of the jth index in the ith scheme

The weight of each index is calculated by entropy weight method

Weight of each index: $w = (w_1, w_2, \cdots, w_m)$

- Quantify each index in the same degree, and calculate the proportion pij of the ith scheme index value of the jth index.
- Calculate the entropy value of the JTH index, Ej.
- Calculate the difference coefficient gj of the jth index.
- The weight can be calculated by normalizing the difference coefficient.

Build a comprehensive evaluation model: $FB_j = \sum_{i=1}^{m} w_i b_{ij}, (j = 1, 2, \cdots, n)$

The index weight table of the food system evaluation system is shown below:

First-level indicator	Second-level indicator	Weight	Three-level indicator	Data type	Weight
Food System Assessment	Sustainable development	0.35	Environmental stress	Efficiency	0.6231
			Ratio of cultivated land to forest	Efficiency	0.1603
			Ecosystem service value	Cost	0.2166
	Fairness	0.25	Index of waste	Cost	0.4341
			The hunger index GHI	Cost	0.115
			The proportion of food consumption	Cost	0.1235
			Per capita direct food consumption	Efficiency	0.0948
			Indirect food consumption per capita	Efficiency	0.0971
			Changes in grain circulation costs	Cost	0.0772
			Urban-rural income ratio	Cost	0.0583
	Economic profit	0.2	Grain output	Efficiency	0.4102
			Food profits	Efficiency	0.2684
			Proportion of grain imports	Efficiency	0.1172
			Agricultural water consumption	Cost	0.0254
			Labor cost ratio	Cost	0.0976
			Pesticide and chemical fertilizer ratio	Cost	0.0812
	The efficiency of the system	0.2	Rural labor force	Efficiency	0.2759
			Total power of agricultural machinery	Efficiency	0.2156
			Natural disasters	Cost	0.2026
			Railway mileage	Efficiency	0.1458
			Highway mileage	Efficiency	0.1601

2.3 Prediction Model: DSPTDGM

2.3.1 Assumptions

The influencing factors of the indicators of the food system are too complex, which are restricted by various policies, environment and culture, and may produce breakpoints of data at some time points.

Therefore, when predicting the main variable and selecting the relevant factors, we assume that the main variable is less affected by other factors, and assume that there will be no breakpoint of data within a certain period of time, and other factors such as economic and policy are relatively stable.

Because of the complexity of the influencing factors of the indicators, we can only select a limited number of variables as the relevant factors. We must also assume that these factors can well determine the trend of the main variables, and these related factors are stable within a certain period of time.

To sum up, it is assumed that:

- the main variable is less affected by other irrelevant factors
- The main variable will not produce breakpoints of data in a certain period of time
- economic, policy and other factors are relatively stable
- The related factors can well determine the trend of the main variable
- the related factors are stable within a certain period of time

2.3.2 Symbol table

Table 1: symbols table

symbols	Defination
$x_1^{(0)}$	the main variable
$x_i^{(0)}, i > 1$	the relevant variable
$x_i^{(1)}$	First order cumulative generation
$z_1^{(1)}$	the nearest mean sequence of $x_1^{(1)}$
λ_i	Time delay factor
k	No.k time point
n	the length of x_i
N	the number of variables
Y	a matrix created by $x_0^{(1)}$
B	a matrix created by $z_1^{(1)}, \lambda_i, x_i^{(1)}$
p	a matrix created by Y and B
a	a parameter obtained through by matrix p
h_1, h_2	two parameters through by matrix p
b_i	variables through by matrix p
$\mu_1, \mu_2, \mu_3, \mu_4$	four parameters obtained through the calculation of parameter a and parameter h_1, h_2
M	the number of particles
$MAPE$	Mean Absolute Percentage Error
X_i	coordinate of No.i particle
V_i	velocity of No.i particle
W	Inertia weight
W_{max}, W_{min}	maximum of Inertia weight and minimum of Inertia weight
C_1, C_2	Two learning factors
C_{max}, C_{min}	maximum of learning factor and minimum of learning factor
P_i	Historical optimal solution No.i particle
P_g	Global optimal solution
$r_1, r_2 \in [0, 1]$	Two randomly generated parameters
ep	current epoch
$maxEpoch$	maximum of epoch

The image above is a symbol table which contains all symbols used in the model can be divided into time response symbols and particle swarm optimization symbols.

2.3.3 Create Model and Analysis

This model is named DSPTDGM, is abbreviation of “Dramatic weight and feature-Simulated annealing algorithmParticle swarm optimization-Time Delay Grey Model”, which is divided into two parts: time response and particle swarm

The development of agricultural indicators is not achieved overnight, but will continue to have an impact in a number of time points, that is to say, there will be a certain delay. In order to reflect the time response, the ordinary grey prediction model adopts the following differential equations:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u$$

This differential equation is obtained by a large number of theoretical calculations and appropriate assumptions. In order to make the grey prediction model simple and solvable, it is stipulated that variable u is a constant, and the following time response formula is derived:

$$x^{(1)}(k+1) = [x^{(1)}(1) - \frac{u}{a}]e^{-ak} + \frac{u}{a}$$

In the formula, the first-order cumulative estimated value of the time point $k+1$depends on the initial value, time development coefficient $a$and development grey number u.

This clearly confirms the limitations of the grey prediction model, which can not be applied to all kinds of data distribution, and sometimes its error will be very large.

Considering that using only two parameters(u,a) is not robust to predict data, we first need to introduce more parameters. Secondly, because the basic grey model only depends on the existing data of the variables that need to be predicted, it can not be directly used in the prediction of the indicators of the food system. The influencing factors of these indicators are not single and independent, we can not ignore the correlation between variables. Therefore, we need to improve the grey prediction model, so that it has the two characteristics of "multi-parameter" and "multi-variable".

By consulting the relevant literature, we find that TDAGM[3] has good properties and satisfies the two conditions: "multi-parameter" and "multi-variable ".

The time response:

$$\hat{x_1}^{(1)}(k) = \sum_{v=1}^{k-1}[\mu_1\mu_2^{v-1}\sum_{i=2}^{N}\sum_{j=1}^{k-v+1} b_i\lambda_i^{k-j}x_i^{(1)}(j)] + \sum_{w=0}^{k-2}\mu_2^w[(k-w)\mu_3+\mu_4] + \mu_2^{k-1}\hat{x_1}^{(1)}(1), k = 2, 3, ..., n.$$

$$\mu_1 = \frac{1}{1+0.5a}, \mu_2 = \frac{1-0.5a}{1+0.5a}, \mu_3 = \frac{h_1}{1+0.5a}, \mu_4 = \frac{h_2 - 0.5h_1}{1+0.5a}, \hat{x_1}^{(1)}(1) = x_1^{(1)}(1)$$

Parameters $a, h1, h2$ and b_i constructed by the following matrix:

$$Y = \begin{bmatrix} x_1^{(0)}(2) & x_1^{(0)}(3) & \cdots & x_1^{(0)}(n) \end{bmatrix}^T$$

$$B = \begin{bmatrix} -z_1^{(1)}(2) & \sum_{j=1}^{2}\lambda_2^{2-j}x_2^{(1)}(j) & \cdots & \sum_{j=1}^{2}\lambda_N^{2-j}x_N^{(1)}(j) & \frac{3}{2} & 1 \\ -z_1^{(1)}(3) & \sum_{j=1}^{3}\lambda_2^{3-j}x_2^{(1)}(j) & \cdots & \sum_{j=1}^{3}\lambda_N^{3-j}x_N^{(1)}(j) & \frac{5}{2} & 1 \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\ -z_1^{(1)}(n) & \sum_{j=1}^{n}\lambda_2^{n-j}x_2^{(1)}(j) & \cdots & \sum_{j=1}^{n}\lambda_N^{n-j}x_N^{(1)}(j) & \frac{2n-1}{2} & 1 \end{bmatrix}$$

$$p = (B^T B)^{-1} B^T Y = \begin{bmatrix} a & b_2 & \cdots & b_N & h_1 & h_2 \end{bmatrix}$$

We have the following analysis: first we observed that a and h are obtained via p, and p are calculated by B , then we know a, h are closely related to B, which is closely related to λ_i, so a, h is a function of λ_i, and the parameters of the whole time response are only λ_i, we can choose the appropriate $\lambda_i$to fit the existing known data. To judge the degree of fitting, we use the $MAPE$, namely, the average percentage error. The calculation method is as follows:

$$MAPE = \frac{1}{n-1} \sum_{k=2}^{n} \frac{|\hat{x_1}^{(0)}(k) - x_1^{(0)}(k)|}{x_1^{(0)}(k)}$$

Our goal is to find out A set of minimum values of λ_i. This is an extreme value problem of multivariate functions, and we use Particle swarm optimization algorithm to solve it.

Let's consider $\lambda_i$as $N-1$dimensional vector of Euclidean space. Let's suppose M particles in this space and set their initial positions:

$$X_i = (x_i^1, x_i^2, \cdots, x_i^{N-1}), x_i^D \in [0,1], D = 1, 2, \cdots, N-1$$

And set the initial velocity:

$$V_i = (v_i^1, v_i^2, \cdots, v_i^{N-1}), v_i^D \in [0,1], D = 1, 2, \cdots, N-1$$

The dimension range of the initial position is set to $[0, 1]$, because $\lambda_i \in [0, 1]$, each dimension of the initial velocity should not be too large, otherwise it will be easy to let the particle converge outside the dimension range of the position.

The iterative formula of the fundamental particle swarm optimization algorithm is:

$$V_i = W * V_i + C_1 r_1 (P_i - X_i) + C_2 r_2 (P_g - X_i)$$

The shortcoming of ordinary particle swarm optimization algorithm is easy to fall into local optimal solution, in order to solve this problem, we can refer to a dynamic inertia weight W, adopt the strategy of nonlinear quadratic curve falling drops (differential strategy), which makes particles easy to scan globally at the beginning of iteration and converge to the global optimal solution at a later stage. We also use a dynamic learning factor to optimize algorithm at the same time in order to jump out of local optimal solution in a timely manner and using the ideas of simulated annealing to receive worse fitness values with a certain probability. the improved iterative formula is:

$$V_i = [W_{max} - (W_{max} - W_{min})(\frac{ep}{maxEpoch})^2] * V_i + [C_{max} - (C_{max} - C_{min})\frac{ep}{maxEpoch}][r_1(P_i - X_i) + r_2(P_g - X_i)]$$

Through the above simulated annealing dynamic weight particle swarm algorithm, we can get a group of $\lambda_i$that minimizes $MAPE$, and substitute it into the time response formula, and let k take a larger time point, then we can get a group of predicted values generated by first-order summations, and then we can get the real predicted values by using the forward subtraction method.

Due to particle swarm optimization algorithm itself is very easy to fall into local optimum and the law of agricultural data change with time is not very obvious, there are many locally optimal solutions existed within the solution space, or a bunch of minima, but we are looking for the least ,so we must made several attempts to this algorithm to get a series of results and select of most optimal one.

In general, the $DSPTDGM$ model is based on the $TDAGM$ model, solved by particle swarm optimization, and optimized by differential descending dynamic inertia weight, dynamic learning factor, and simulated annealing.

3 Optimized for equity and sustainability

3.1 Changes in developed and developing countries after optimization

In order to detect changes in supply-side production structures in countries at different levels of development, we need to select a developed country and a developing country. China and the United States are the most macroscopically comparable group of countries. Therefore, developed countries we choose the United States, developing countries we choose China.

The United States is a highly intensive country, relatively rich, export-oriented; China is a country with a low degree of intensification, a moderate level of development and an import-oriented economy. So let's set the parameters as shown in the figure below. We set the United States up as an exporter, mainly corn; China is set as an importer, mainly for wheat.

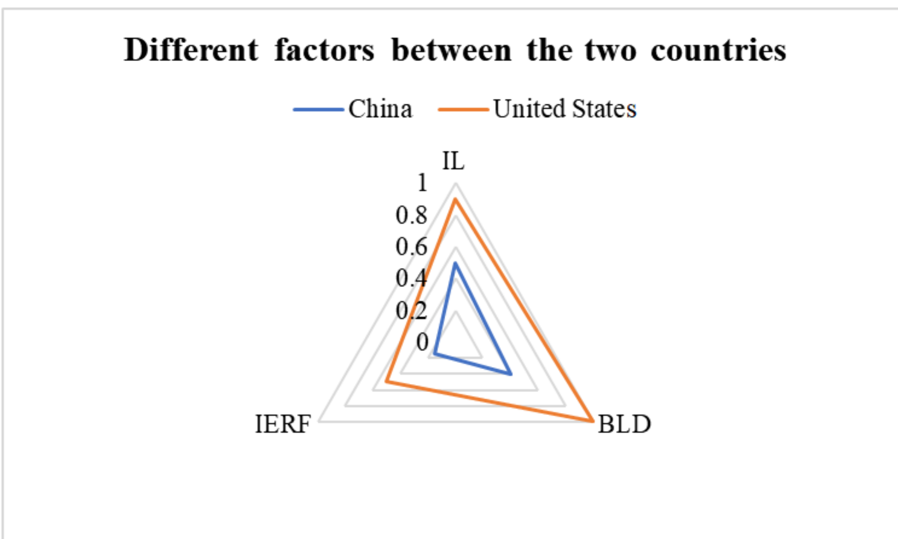

Figure 7: Different factors between China and U.S.

The chart below shows China and the US PPU,LPU,YPU. The data came from the local statistics bureau and the Ministry of Agriculture. From the chart, we can see the difference between developing countries and developed countries:

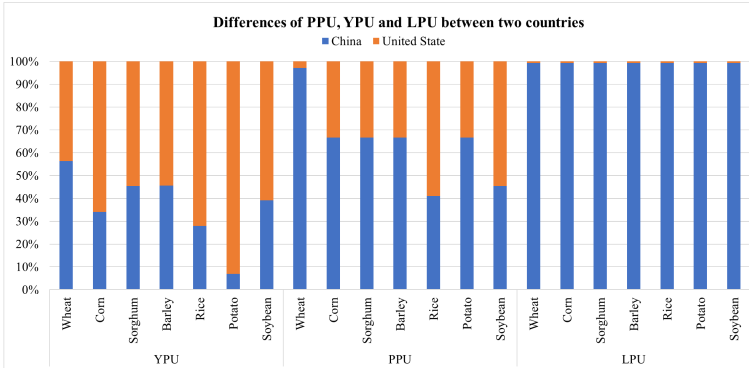

Figure 8: Comparison of Chinese and American Agriculture

- Compared with developed countries, the degree of agricultural intensification in developing countries is lower and the planning elasticity is poor.
- Compared with developed countries, developing countries have a lower level of science and technology and lower output per unit area.
- Low productivity in developing countries; Food profits in developed countries are low, which makes it competitive for food exports.

3.1.1 Changes and differences in target indicators

Put the data into the model. The indicators of profit, yield, balance and environmental pressure under different priorities are obtained, as shown in the figure below.

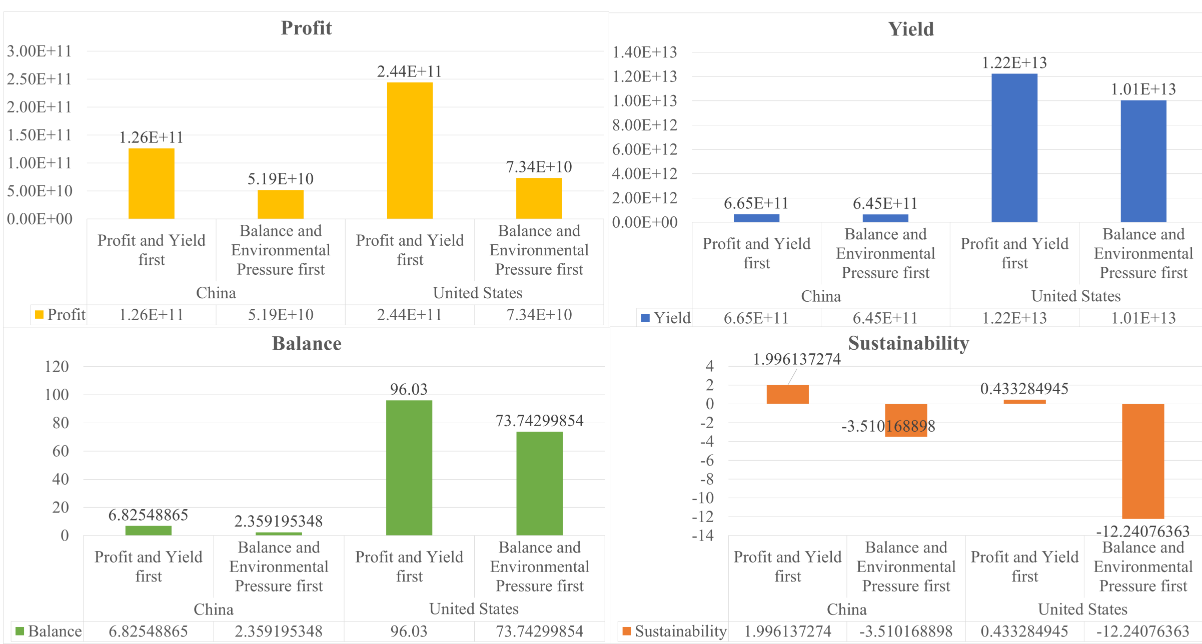

Figure 9: Changes in four indicators

In the case of environmental pressure and equilibrium priority, both profits and total output have declined, and the balance and environmental pressure have eased. The United States is far ahead of China in environmental friendliness, profits, and production. In terms of balance, although the waste index decreased under the premise of equilibrium priority, the waste index was still as high as 73.7 after optimization. This suggests that in developed countries, the waste of supply caused by high capacity is large and can be mitigated appropriately by changing the structure of production. At the same time, the United States sustainable development first can also bring huge benefits to the environment.

However, balance is not a critical issue for developing countries. As can be seen from the data, China's waste index only decreased by about 4 points. Therefore, it can be seen that the improvement brought by the priority equalization of developing countries is very limited, and equalization is not suitable for developing countries as a high-priority goal.

3.1.2 The change and difference of grain production structure

The following figure shows the new food production structure under different priorities:

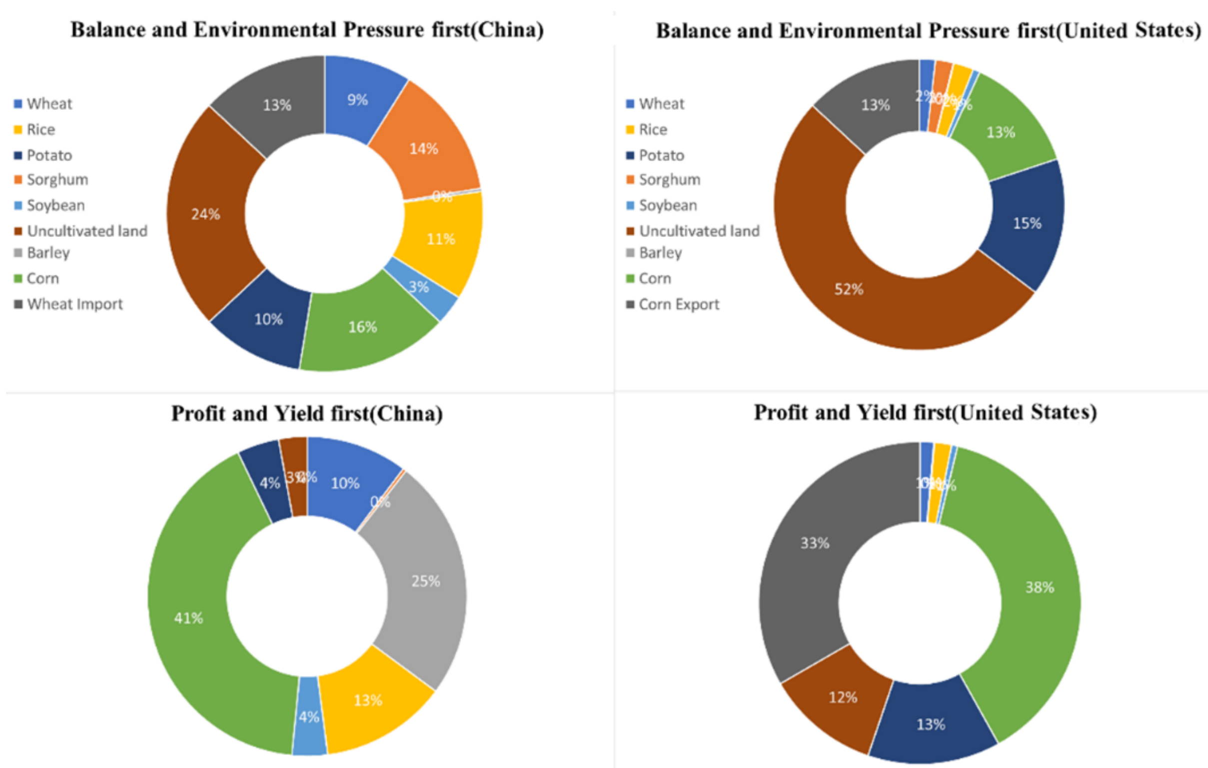

Figure 10: The proportion of agricultural components

Under the circumstance of environmental pressure and equilibrium priority, the two countries give up part of cultivated area to reduce the pressure on the environment; At the same time, the proportion of high-yield crops will be reduced to reduce waste. The production structure of the United States has been greatly adjusted, with the area not under cultivation increasing by 40%. This is caused by the high degree of intensification. In China, however, the adjustment in the production structure was relatively small, with non-cultivated area increasing by only 21%. This is precisely because of the low degree of intensification of production structure change ability is poor. Compared with the United States, China, as a developing country, produces far less grain than the United States and cannot support the food shortage caused by the conversion of farmland to forests, so it needs to import grain to meet the basic needs of the country. And that led to the recession. In other words, developing countries that put too much emphasis on sustainable development may hurt agricultural economies.

3.1.3 Changes and differences in livestock production structure

The figure below shows the change of livestock total under different priorities

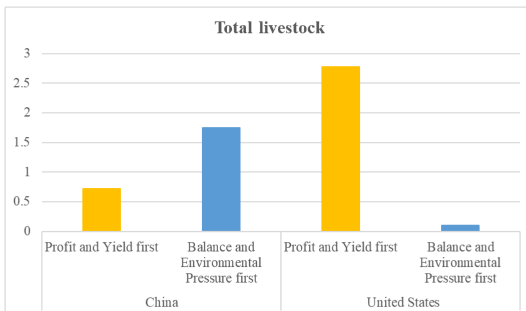

Figure 11: The total amount of livestock

As you can see, the total number of livestock in the United States has declined dramatically. In fact, livestock farming is a highly environmentally unfriendly industry. This could explain the decline in U.S. livestock stocks. This shows that the level of livestock production in developed countries is placing a very high strain on the environment.

The following figure shows the new livestock production structure with different priorities.

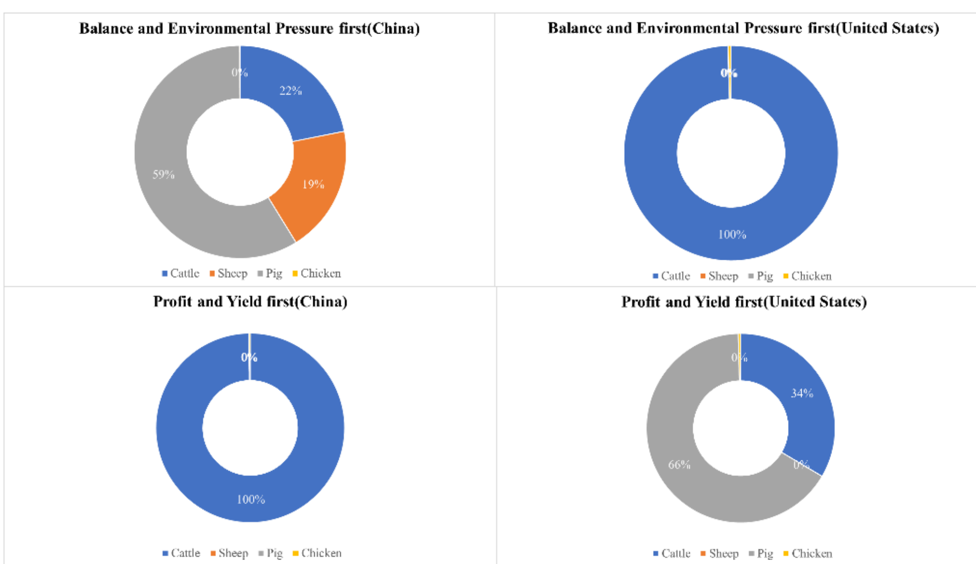

Figure 12: The proportion of components in various livestock

It can be seen that although the total number of livestock in China has increased, there has been more of a shift from raising high-stress livestock (cattle) to low-stress livestock. A developing country like China cannot reduce its total as much as the United States. In order to meet the daily dietary needs of meat in society, the total amount of livestock cannot be reduced. It also illustrates the negative economic impact of high priority equalization and sustainable development on developing countries.

3.2 How soon will the new food system be implemented

Since the data is not sufficient, we consider constructing the data with reasonable assumptions.

Growth curve can well describe the law of development of things, we assume that things by active function, passive function and perturbation function, active function is the natural growth curve, passive function is our is obtained by integrating a more conform to the objective laws of human disturbance function, we select a random disturbance function strong function. We can construct some data by using the following functions to simulate the development of things.

$$y = \frac{a}{\frac{1}{2} + 2^{x+1}} + b\sqrt{2t} + rand() * sin(n * rand() * t) + rand() * sin(n * rand() * t)$$

The points generated by this function are processed linearly so that they fall within the region where the index changes. Then we generate data for the next five years through this function, and then use DSPTDGM model to continuously predict future data until the data meet the conditions

Prediction of the Equitable and Sustainable Optimization of the American Food System:

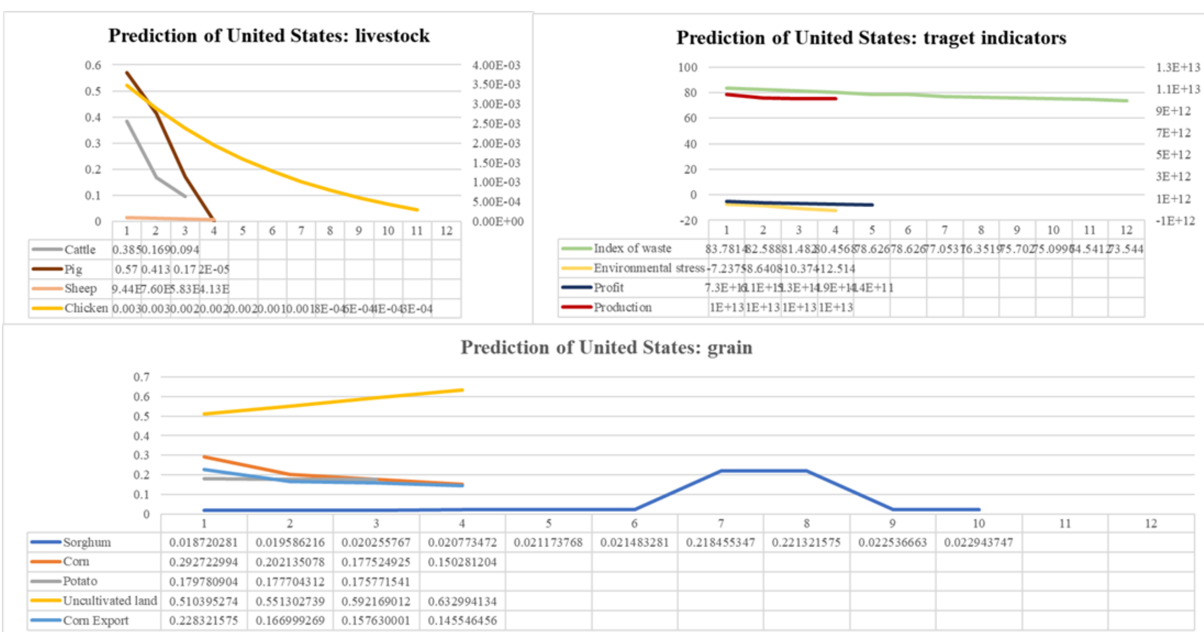

Figure 13: Predication of U.S.

Prediction of the Equitable and Sustainable Optimization of the China Food System:

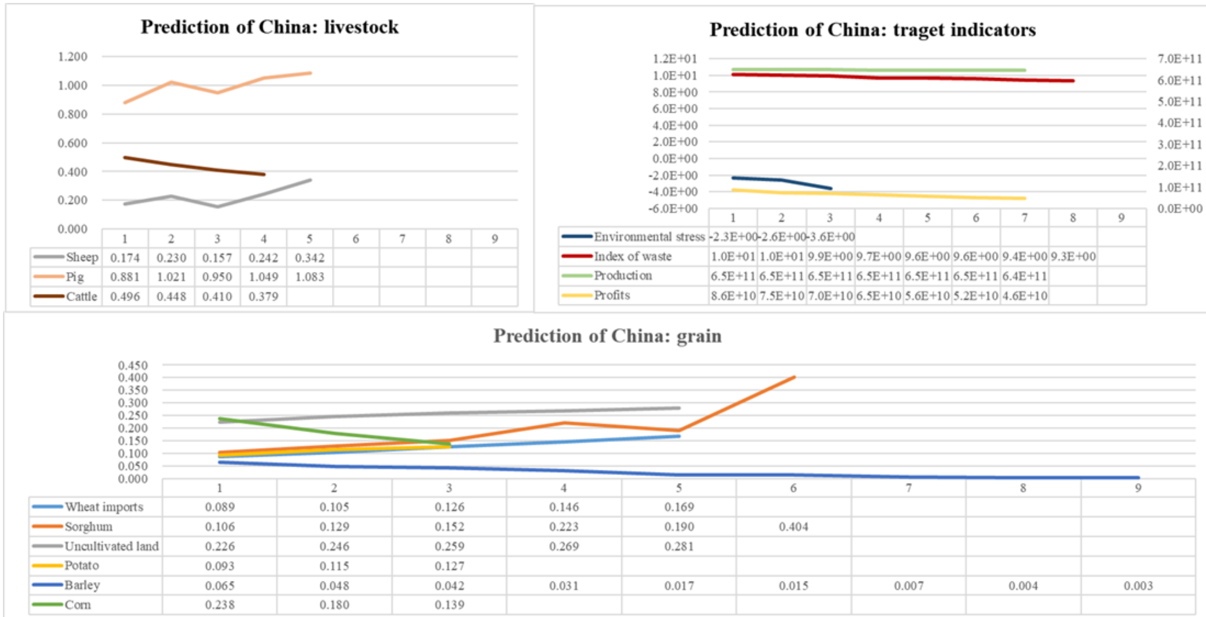

Figure 14: Predication of China

According to the results of the table, it will take at least 14 years for China and 18 years for the United States to complete the priority shift

4 Change the priorities of the food system

4.1 The benefits and costs of changing the order of supply

Benefit: Changing the priorities of the food system will focus more on the environmental problems caused by agricultural production. After prioritizing sustainable development, China's sustainable development index score increased by 19.1%, and the United States' sustainable development score increased by 14.9%. Greenhouse gas emissions from agriculture, the use of arable land, the use of water, and the use of phosphorus and nitrogen from agricultural fertilizers will all decrease. The second concern is fairness. The hunger index GHI and the proportion of food waste will decrease. After the fairness priority is improved, China's score of equity index will increase by 12.8%, and that of the United States will increase by 13.0%.

Cost: focus on sustainable development of resources, do not advocate planting some crops that have a great impact on the environment, and do not advocate excessively high land use rate, so the existing economic benefits will decline. This kind of influence is acceptable to developed countries, but for some developing countries, improving the priority supply order of sustainable development will cause a great decline in economic benefits, which will have a great impact on developing countries.

4.2 How long will it take to happen

4.3 The difference between developed and developing countries

Through the fuzzy comprehensive food system evaluation system model

On a scale of 0 to 1, the higher the better

region	year	Sustainable development	fairness	Economic profit	The efficiency of the system	Comprehensive score (0-1)
China	2020	0.414	0.612	0.622	0.532	0.529
China	2034(longest)	0.605	0.74	0.432	0.686	0.621
US	2020	0.496	0.613	0.674	0.684	0.598
US	2039(longest)	0.644	0.743	0.616	0.742	0.683

The United States: The United States saw some improvement in its sustainability index and equity index after the increase in its sustainability priority, but the economic profit index of the United States decreased by about 8.5%. For the United States, large-scale high-tech agricultural production, the output value is far higher than that of developing countries, and its highly developed agriculture is less than developing countries for the destruction of the environment, so the sustainable development index in change the food system supply priority order after improved, but there is no big developing countries. The SDG constraints have taken some toll on the economic profits of the US food system, but they are tolerable. The overall score for the U.S. food system also increased.

China: After prioritizing sustainable development, China's sustainable development index has increased by more than 30%, China's equity index has also improved, and China's economic profit index has dropped by nearly one third. Such a sharp decline is very unfavorable for developing countries. The reason why China's sustainable development index has improved so much is that the construction of sustainability in China is not perfect at present, and there is still much room for improvement. However, the focus on environmental protection has resulted in the decline of economic profits, which also reminds us that the change of the food system is not an immediate task. It takes time, and in this process, we need to make analysis based on the national conditions and make trade-offs. The overall score of China's food system has improved somewhat.

5 A Summary

5.1 Models evaluation

No matter the scale and nature of the system, we can use the indicators defined by the evaluation model to complete the evaluation, or use the prediction model to complete the prediction of data. This is because the design of evaluation indicators is universal, so long as they are provided with the right data, they can produce reasonable results. Both the evaluation model and the prediction model use the data of the supply side model as the basis. Therefore, the primary task of the model applied to different food systems is to make the results obtained from the supply side model as close as possible to the real situation.

5.1.1 scalability

The supply side model uses multi-objective nonlinear programming. This means that the model can design constraint parameters according to requirements or add constraints to fit the local food system as much as possible. For a larger system, the assumptions of the model are still valid; However, the granularity of some constraints is too small, which can be considered to be removed in a larger model. Only very limited modifications to the existing ones are required.

For a smaller system, some of the assumptions of the whole model are no longer valid as the system starts to become more detailed and complex. This does not mean that the model is no longer valid. It only needs to add more impact factors and constraints to make the model effective again, but this requires a huge amount of work.

5.1.2 adaptation

By means of productivity, output, economic value and intensification factor, the model has realized a very perfect description of regional characteristics. Therefore, even if the region is changed, as long as the relevant factors are set, the model can work very effectively in the premise of other regions.

However, the whole model needs full and complete data to be supported in order to work effectively. For some regions, especially poor ones with very limited information, the lack of such data may prevent the model from doing its job well.

5.1.3 sensitivity analysis

DSPTDGM is a time series model of grey prediction. In order to verify the correctness of DSPTDGM, we selected the total output of various kinds of grains and vegetables in China from 2010 to 2017 as the sample, and asked DSPTDGM to predict the total output of various kinds of grains and vegetables in 2018. The final calculated MAPE is 4.94%. The accuracy rate of DSPTDGM reached 82.6% under the premise of 10% tolerance to error, which proved that the model had relatively stable prediction ability.

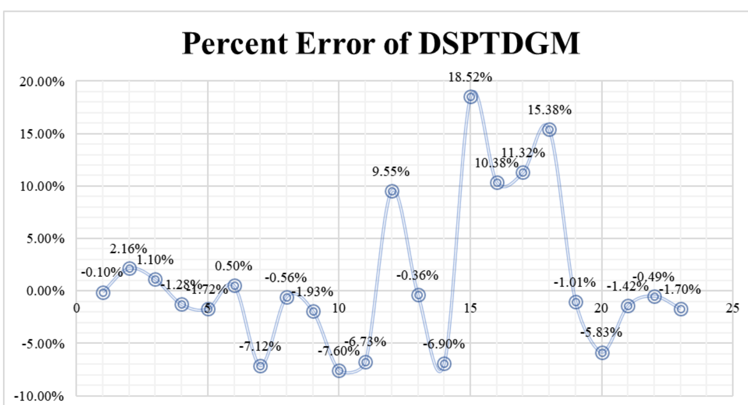

Figure 15: Percent error of DSPTDGM

In this model, there are grazing constraints. As for the coefficient of X_12in the constraint inequality, we assume it to be -1, indicating that there is no other grassland except the uncultivated area. If it is greater than -1, it means there are other grasslands. Then the sensitivity of the coefficient of grazing constraint was analyzed.

Let's set this coefficient as $-R$, keep the consistency of other parameters, and constantly modify the size of R to obtain the following $profit - R$relationship:

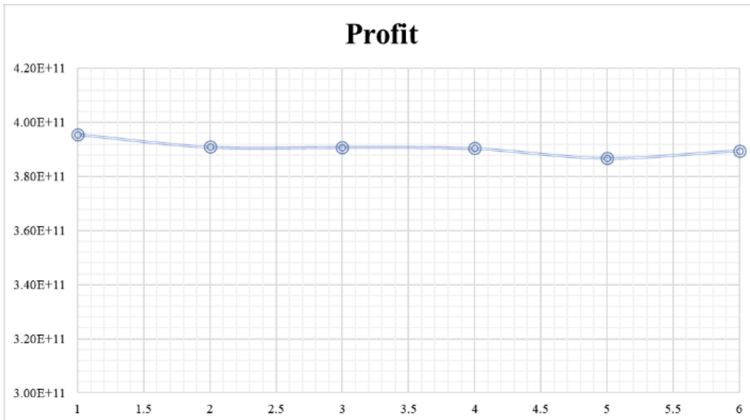

Figure 16: Profit and R relationship

5.2 Promotion of relevant policies

Optimize the sustainability of the food system, plant according to the planting proportion of main crops calculated by the newly established food system, rationally arrange the planting area of each crop, improve the ecological environment of cultivated land, and comprehensively guide the cultivation of current agricultural products. In addition, we will ensure the quality of agricultural water, strengthen water pollution control, and fully implement measures to protect and restore the ecological environment of water sources. We should establish strict standards for the rational use of pesticides, vigorously promote the rational use of pesticides and the harmless treatment of pesticide packaging wastes, and reduce the harm of pesticides to the ecosystem[4]

Optimize the fairness of the food system, establish a direct food subsidy system within the region, with the regional intervention goal of combining a variety of supporting measures such as direct food subsidy, price support and quota production, so as to make the overall balance of food distribution within the region and eliminate the number of hungry people within the region as far as possible. Inter-regional humanitarian agencies, such as the World Food Programme (WFP), encourage food aid from developed regions to underdeveloped ones, and take steps to ensure food supplies for those less fortunate in crises or natural disasters [5]. Under the new model of the food system, we predict that in 10-20 years, there will be a significant reduction in the number of hungry people in the world, and a significant reduction in areas of extreme poverty. The figure shows the projected global GHI index distribution table.

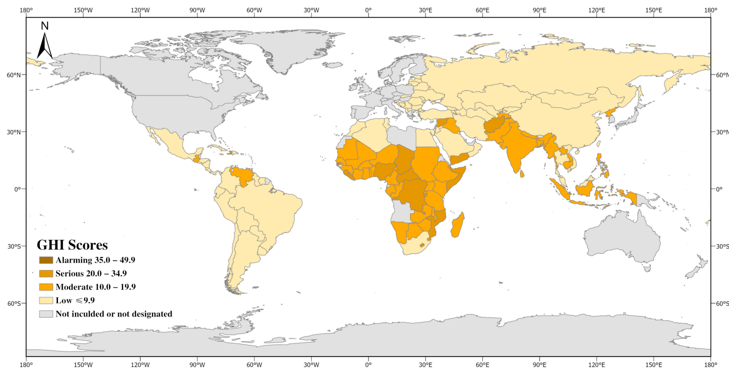

Figure 17: Global hunger index estimates

Improve the economic profit of the food system, according to the newly established food system model, optimize the planting proportion of crops, and improve the economic benefit without harming the environment. We should make use of the production advantages and advanced experience of the developed agricultural areas to drive the grain development of the backward areas and enhance the production level of the whole country and region. Technological progress has an obvious effect on the efficiency of agricultural resource allocation, so it should be further promoted. Therefore, countries and regions should increase support for agricultural science and technology research and development, optimize the expenditure structure of financial support for agriculture, put more funds into agricultural science and technology research and development, establish a stable agricultural science and technology support mechanism, drive agricultural science and technology progress through innovation, and improve economic profits [6].

Improve the system of food system efficiency, technical efficiency is the influence factors of the system efficiency of the food system, need to improve the efficiency of technology, the innovation and the agricultural technology research and development results should be used in agricultural production, integration of agricultural science and technology resources, encouraging agricultural production operators to adopt new technology, new equipment, strengthen the agricultural science and technology research and development institutions and agricultural production and operation of technology cooperation, provide the necessary technical guidance, agricultural technology promotion in the field of agricultural production, improve the utilization efficiency of agricultural resources [6]. With the increasing amount of grain circulating between the main producing and marketing areas, more efficient and cheaper means of grain transportation are needed. The bulk grain logistics transportation mode of "bulk, bulk unloading and bulk transportation" has the advantages of high transportation efficiency, low loss and short cycle, which is the development trend of grain circulation. Therefore, it is suggested to strengthen the promotion of this decentralized logistics transportation mode [7].

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