

# Evaluation and Analysis of Food System Based on ESE Model

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**Abstract:** In order to better analyze the food system and alleviate hunger, we mainly design an ESE model. First, we select 16 indicators from three fields: economic, social and environment. After data processing and weight calculation, we obtained long-term and short-term scores of a food system. We analyze three typical food systems in the world today and select a countries for analysis. Finally, we analyze the **sensitivity** of the intervention model.

**Keywords:** Weight Calculation Method, Intervention Model, Sensitivity.

## 1. Introduction

Zero Hunger, goal 2 of the SDGs, promises to end hunger, achieve food security, improve nutrition and promote sustainable agriculture, which is also the primary work of the WFP.

However, the current food system, which allows food to be produced and distributed relatively cheaply and efficiently, prioritizes efficiency and profitability. Although the system is highly efficient, it has resulted in serious inequities and a residual environmental footprint.

To better achieve the goal of zero hunger, and to address the inequity and unsustainability of the current food system, it is imperative to reimagine and reorder the priorities of it. Therefore, we design an ESE model to solve this problem.

## 2. Economics- Social- Environmental Model

In assessment of the food system of in a country, we need to consider many factors to comprehensively reflect the efficiency, profitability, sustainability and equity of it.

In this paper, We have determined sixteen main factors. These factors can be divided into three main fields: economics, social and en-vironmental. We will first explain how to quantify the influence of each factor, then describe how to determine the weight of each indicator and how to process data, and finally calculate the in different countries.

### 2.1. Economics

Here are six economic indicators that directly measure the level of food production and consumption in a country. And then, they can represent the efficiency and profitability of the food system. We only consider the economic indicators most closely related to the food system and ignore other minor factors.

#### 2.1.1. Food Available Per Capita

The amount of food available per capita is the foundation of a robust food system. Only do ensure the amount of food available per capita can further discuss the food consumption capacity. Therefore we can choose the food production index,  $x_1$  ( + ), to represent the amount of food available per capita.

#### 2.1.2. Food Expenditure

Food expenditure is a direct reflection of a country's ability to consume food. Food consumption is basic and does not augment with an increase in income or consumption. Engel's coefficient refers to the proportion of food expenditure in total living expenses in a household, which decreases with the increase of family income.

Since it is not easy to obtain the data of food expenditure, we use the product of Engel's coefficient and the total living expenditure of residents to quantify the food expenditure index( + ). The calculation is shown in Eq.1.

$$x_2 = \text{Engel's Coefficient} \times \text{Total Living Expenses} \quad (1)$$

#### 2.1.3. Food Prices

Like food expenditure, food prices directly show the food consumption capacity of a country, too. Therefore, we choose the food price index( \* ),  $x_3$ , to represent the food prices.

#### 2.1.4. Food Diversity

The main types of food vary from country to country. We set the food consumption diversity degree( \* ),  $x_4$ , to quantify the level of food consumption structure. The calculation formula can be seen in Eq.2.

$$x_4 = \frac{\text{meat} + \text{egg} + \text{dairy}}{\text{grain} + \text{vegetable}} \times 100\% \quad (2)$$

Where, *meat* is proportion of meat, fish and aquatic products, *egg* is proportion of eggs and egg products, *dairy* is proportion of dairy and dairy products, *grain* is proportion of food crops like wheat, rice and corn, *vegetable* is proportion of vegetables and fruits.

#### 2.1.5. Food Sources

Food sources include both domestic production and import. We use the proportion of imported food to total food( \* ),  $x_5$ , to indicate the degree of diversity of food sources.

#### 2.1.6. Agricultural Development

Agriculture is the basic industry that provides support for

the construction and development of national economy, and agricultural development is the foundation of a country's food system. We choose the agricultural mechanization level( + ),  $x_6$ , to quantify the agricultural development of a country.

The calculation expression for economics index of our ESE model is:

$$Economics = \alpha_1 x_1 + \alpha_2 x_2 + \alpha_3 x_3 + \alpha_4 x_4 + \alpha_5 x_5 + \alpha_6 x_6 \quad (3)$$

## 2.2. Social

We use six social indicators to quantify the impact of society on food system. These social indicators are required to reflect the equity of the country in terms of food production, distribution and consumption.

### 2.2.1. Vulnerable Groups Food Security

The food security of vulnerable groups is an important factor to measure the equity of the food system. The more equal the food system is, the more guaranteed the food of vulnerable groups will be. When people have less real income, they spend less on food and adjust their consumption accordingly. The effect gets stronger with less income, which means life gets harder for the vulnerable. Clearly, the food security of vulnerable groups is directly related to the vulnerable employment rate( + )  $y_1$ . In addition, in order to quantify the food security of vulnerable groups, the government subsidies,  $y_2$  ( \* ), should also be considered.

### 2.2.2. Food Nutrition

Food insecure means being without reliable access to sufficient affordable and nutritious food. We can process the data related to food insecurity to measure the food nutrition of the country. At the same time, the United Nations focuses on the welfare of children. So, we also take the impact of the proportion of healthy children under five into account. Eq.4 is used to quantify residents' food nutrition level( + ),  $y_3$ .

$$y_3 = 50\%(1 - severe) + 50\%(1 - undernourishment - overweight) \quad (4)$$

Where, *severe* is the prevalence of severe food insecurity in the population (%), *undernourishment* is the prevalence of undernourishment (% of children under five), and *overweight* is the prevalence of overweight, (% of children under five)

### 2.2.3. Food Policy

Compared with higher-income countries, lower middle-income countries are less suited to national food policies, resulting in huge differences in the structure of food systems. We will combine the data of CPIA policies for social inclusion/equity cluster average retrieved from the *World Bank* database with the actual situation of national food policies, and then give a score( + ),  $y_4$ , from 1 (lowest) to 6 (highest).

### 2.2.4. Conflict( - )

More than half of the hungry people around the world live in countries affected by conflict. If poverty, unemployment or economic hardship strike at the same time, hunger can exacerbate the conflict. The vicious cycle of conflict and

hunger must be broken if we are to create a world of food security for all, as Eq.5.

$$y_5 = dead + displaced + refugee \quad (5)$$

Where *dead* is the battle-related death toll, *displaced* is the displaced persons by conflict and violence, *refugee* is refugee population by country or territory of asylum.

### 2.2.5. Income Gap

The world produces enough food to feed everyone, however, many people in the world still do not have enough income to buy enough food or to obtain nutritious food. Therefore, We use the Gini coefficient( - ),  $y_6$ , to represent the income gap, and then show the food inequality.

The mathematical expression for social indicators in the ESE model equation has a form of:

$$Social = \beta_1 y_1 + \beta_2 y_2 + \beta_3 y_3 + \beta_4 y_4 + \beta_5 y_5 + \beta_6 y_6 \quad (6)$$

## 2.3. Environment

We assign four environmental indicators. These widely used indicators allow us to capture key aspects of the national environmental dimension in food system, which further allows us to assess the sustainability of food system.

### 2.3.1. Food Wastage

Curbing food wastage is critical to sustainability of food system. We use the food wastage degree( - ),  $z_1$ , to represent this indicator.

### 2.3.2. Food Recovery

Food recovery rate( + ),  $z_2$ , refers to the proportion of food actually recycled to the total amount of food wastage. Developing the recycling of wasted food can reduce the impact of food wastage on the environment to a certain extent, thus drawing near to sustainable development.

### 2.3.3. Environmental Footprint

It is important to reduce the depletion of natural resources in the production and consumption of food. We quantify the environmental footprint( - ),  $z_3$  from four aspects: fresh water, soil, greenhouse gas emissions, and biodiversity. Its calculation formula is as follows:

$$z_3 = 25\%water + 25\%soil + 25\%gas + 25\%biodiversity \quad (7)$$

In Eq.7, *water* is the proportion of agriculture freshwater to total freshwater withdrawal, *soil* is the proportion of agricultural land area to total land area, *gas* is the proportion of greenhouse gas emissions caused by food system, and *biodiversity* is the proportion of biodiversity loss caused by food system, respectively.

### 2.3.4. Food Saving Awareness

Food saving awareness plays an important role in the sustainable development of food systems. The general food saving awareness( + ),  $z_4$ , of citizens may be affected by their degree of education, government advocacy, efforts made

by social welfare organizations and so on. In view of the uncertainty of other factors, we will only focus on the first two factors. They are the average degree of education of citizens, *education*, and the government advocacy of food saving, *advocacy*.

$$z_4 = 50\%education + 50\%advocacy \quad (8)$$

The mathematical expression for environmental indicators in the ESE model equation has a form of:

$$Environmental = \gamma_1 z_1 + \gamma_2 z_2 + \gamma_3 z_3 + \gamma_4 z_4 \quad (9)$$

## 2.4. Data Processing

### 2.4.1. Data Acquisition and Preprocessing

We searched databases like *World Bank*, *United Nations World Food Programme* and so on<sup>[11-12]</sup>. And we found basic data for 16 indicators across 126 countries

However, not all data can be collected and statistics for some indicators are lost. In order to improve this situation, we use *SPSS* for data preprocessing.

### 2.4.2. Data Normalization

In the process of analyzing the indicators, we find that all the indicators can be divided into three categories. Tag ‘+’ means that for the indicator, bigger is better. Similarly, tag ‘-’ means smaller is better, and tag ‘\*’ means that the value is better when it is closer to the specific value.

At the same time, all indicators are different in dimension, so they cannot be directly compared. For the convenience of subsequent calculations, we need to standardize these sixteen indicators, converting them into numbers in the range of 0-1.

We will deal with economic, social and environmental indicators as follows:

Let  $r_{ij}$  denotes the  $j$ -th indicator of the  $i$ -th country.

As for indicators those smaller is better tagged as ‘-’, the equation (10) should be:

$$\begin{aligned} \tilde{r}_{ij} &= r_j^{\max} - r_{ij} \\ r_j^{\max} &= \max\{r_{1j}, r_{2j}, \dots, r_{nj}\} \end{aligned} \quad (10)$$

As for indicators those closer to the specific value is better tagged as ‘\*’, the equation (11) should be:

$$\begin{aligned} \tilde{r}_i &= 1 - \frac{|r_{ij} - r_{jbest}|}{M_j} \\ M_j &= \max\{|r_{ij} - r_{jbest}|\}, i = 1, \dots, n \end{aligned} \quad (11)$$

Where  $r_{jbest}$  is the best value of the  $j$ -th indicator.

After unifying all indicators into indexes that bigger is better, we use the following Eq.12 to standardize the indexes, eliminate the dimensionality effect, and convert them into numbers within the range of 0-1.

$$z_{ij} = \frac{r_{ij}}{\sqrt{\sum_{i=1}^n r_{ij}^2}} \quad (12)$$

### 2.4.3. Weights Calculation

Different indicators have different effects on the food system of a country. We look for index data in the fields of economics, society and environment, use the entropy weight method (EWM) to calculate the weights of massive data, and then apply the index after weight calculation to Eq.3, Eq.6 and Eq.9.

EWM is an objective weighting method. The smaller the variation degree of the index, the less information it reflects, and the lower the corresponding weight.

For the normalized matrix  $Z$  that has been processed from the three fields of economics, society and environment, we will calculate their weights,  $\alpha$ ,  $\beta$ ,  $\gamma$ , respectively.

First, we calculate the probability matrix  $P$ , where the Eq.15 for each element  $p_{ij}$  in  $P$  is as Eq.13.

$$p_{ij} = z_{ij} / \sum_{i=1}^n z_{ij} \quad (13)$$

Then, we calculate the information entropy of  $j$ -th indicator, as Eq(14).

$$e_j = -\frac{1}{\ln n} \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (14)$$

Finally, we can get the entropy weight of the  $j$ -th indicator, as Eq(15).

$$q_j = \frac{1 - e_j}{\sum_{j=1}^m 1 - e_j} \quad (15)$$

## 2.5. ESE Score

By calculating the scores and weights of different indicators, we have obtained the scores of economic, social and environmental fields.

We define the scoring formula of ESE as Eq(16):

$$ESE_{score} = \omega_1 \times Economic + \omega_2 \times Social + \omega_3 \times Environmental \quad (16)$$

Through different weight calculation methods, we can get different values of  $\omega_1$ ,  $\omega_2$  and  $\omega_3$ . So, we can evaluate the costs and benefits of a food system from different aspects.

## 3. Impact of Changing Priorities

Different countries have different conditions, so they have different needs for their food systems. We will analyze the necessity to change food system priorities in terms of short-term benefits and long-term costs in the light of practical development needs.

### 3.1. Short-term Impact

In order to better compare the current situation of the food system, we adopt the idea of weighted average method, as shown in Eq.17. And then we can figure out the total score of food system in the short run,  $ESE_{Short\ Score}$ .

$$\begin{aligned}\omega_1 &= \frac{Economics}{Economic + Social + Environmental} \\ \omega_2 &= \frac{Social}{Economic + Social + Environmental} \\ \omega_3 &= \frac{Environmental}{Economic + Social + Environmental}\end{aligned}\quad (17)$$

The weighted average method amplifies the impact of short-term benefits.  $ESE_{Short\ Score}$  calculated after adopting the weighted average can reflect the appearance of the food system in the short term, that is, short-term benefits. Therefore, it is easier to see the superiority of the current system priority selection.

### 3.2. Long-term Impact

In our view, the impacts of economics, society and environment on the food system should trend equally in the long run. So, we define:

$$\omega_1 = \frac{1}{3}, \quad \omega_2 = \frac{1}{3}, \quad \omega_3 = \frac{1}{3}\quad (18)$$

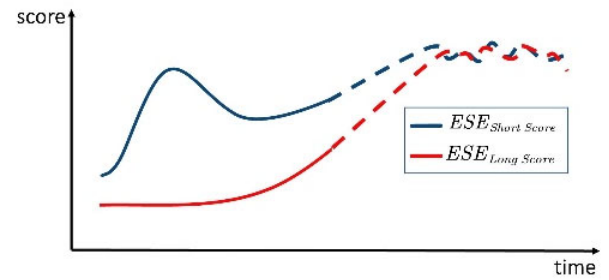
Then we can figure out the total score of food system in the long run,  $ESE_{Long\ Score}$ .

By looking at the  $ESE_{Long\ Score}$  in long-term trends, we can see why countries were intervening, and we can also make recommendations for intervention in countries that are not.

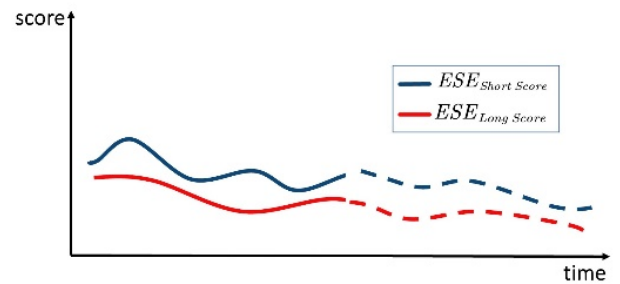
### 3.3. Typical Cases Analysis

We evaluate food systems in terms of both short-term benefits and long-term costs. According to the above ESE model, we calculated the long-term and short-term ESE scores of different countries, that is  $ESE_{Short\ Score}$  and  $ESE_{Long\ Score}$ . And we also predict the general trend according to its scores of *Economics*, *Social* and *Environmental*.

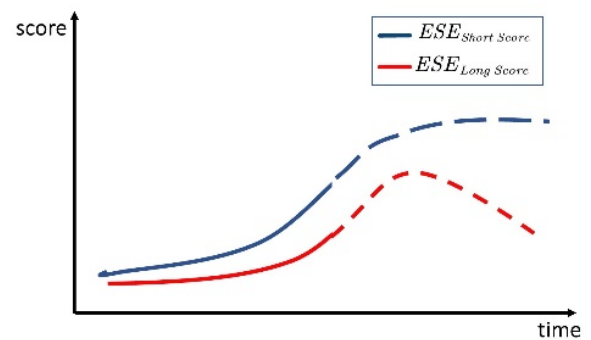
Our model shows a wide range of national food systems, but the overall trend is in three directions. These three typical food systems are selected for our analysis, that is, the typical developed country, the typical developing country in conflict and the typical developing country in stability, as shown in Figure 1.



(a) developed country



(b) developing country in conflict



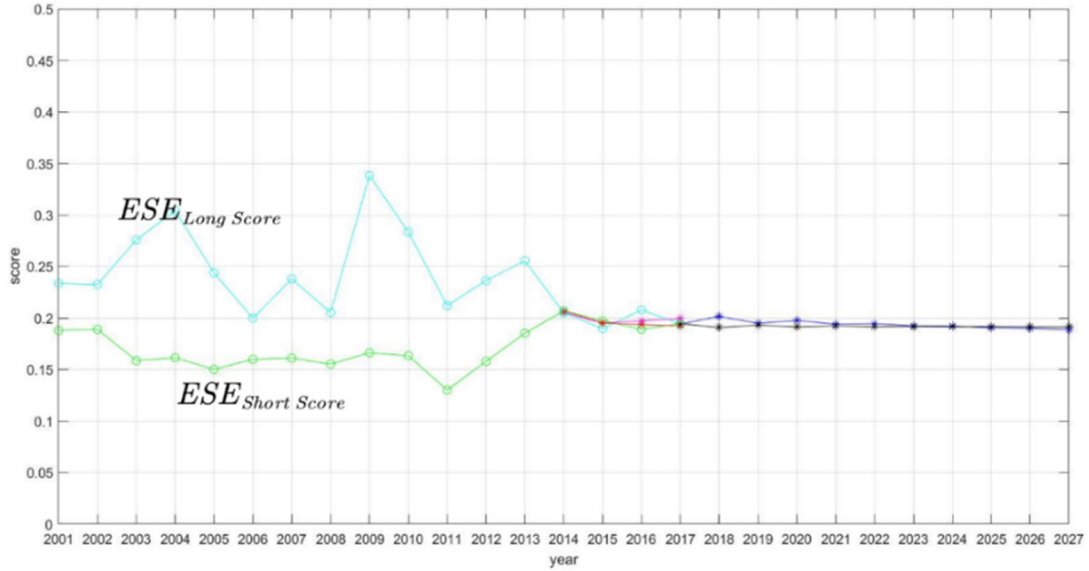
(c) developing country in stability

Figure 1. ESE Scores

Case: Developing Countries in Conflict----- Afghanistan

Some extremely hungry developing countries live in areas of perpetual conflict, where conflict and political instability exacerbate food system instability. In severe areas, the food system is on the verge of collapse due to the conflict, and there is a serious bipolar phenomenon. Compared with other countries, the immediate priority for developing countries in conflict is to solve the problem of hunger and help the vulnerable.

In Afghanistan, for example, with the war, conflict and a healthy diet hidden costs increase, the number of hungry people is on the increase in Afghanistan. As shown in Fig. 2,  $ESE_{Long\ Score}$  and  $ESE_{Short\ Score}$  of the Afghan food system are both low. It is clear that, the Afghan food system is so unstable because of the severe conflict and inequity. It may even be on the verge of collapse in the long run. So, with the aim of alleviating the hunger crisis, it is crucial to optimize the food system of Afghanistan.



**Figure 2.** ESE Scores in Afghanistan without intervention

Based on the actual situation, we present the most effective optimization scheme for improving the food system in Afghanistan.

### 3.3.1. Aid Interventions

Conflicts and wars have weakened the handling ability of government. Therefore, assistance programs from the UN and international organizations must be used to help alleviate the hunger crisis in Afghanistan.

We quantify the level of aid intensity,  $p(t)$ , which reduces the gap between rich and poor, to demonstrate the effectiveness of optimizing food systems. We use the initial value  $p(t_0) = 1$  for the simulation, and we believe that the level of aid intensity will increase to alleviate the hunger crisis. Clearly, social influence decreases over time. Since aid intervention will directly lead to the deceleration of the growth trend of the gap between the rich and the poor, that is, the growth trend of social influence curve  $b(t)$  slows down. We set the following relationship:

$$\begin{aligned} p(t) &= e^{a_p \times (t - t_0)} \\ b(t) &= b(0) + \min(b(0) \times p(t), 0.2) \end{aligned} \quad (19)$$

Here we define  $a_p = 0.5$ .

### 3.3.2. Policy Interventions

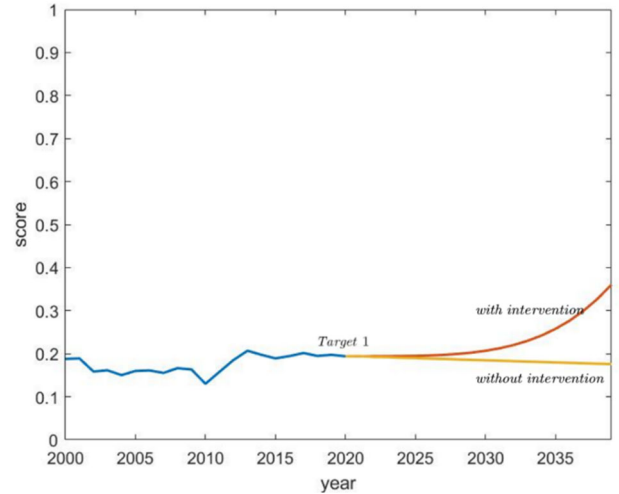
As an agricultural country, agriculture contributes more than one third of Afghanistan economic output. So, making food systems more sustainable is essential. The government should take measures to promote the sustainable development of the food system.

We use  $c(t)$  to simulate the process of increasing policy intensity, which is similar to that of aid interventions. We set the intervention as follows:

$$\begin{aligned} c(t) &= e^{b_g \times (t - t_0)} \\ g(t) &= g(0) + \min(g(0) \times c(t), 0.2) \end{aligned} \quad (20)$$

Here we define  $b_g = 0.3$ .

After integrating the needs of the country to optimize the food system, we get the simulation curve fitting results as Figure 3. Obviously, measures to intervene in the food system of Afghanistan are necessary.



**Figure 3.**  $ESE_{Long Score}$  in Afghanistan

## 4. Sensitivity Analysis

When determining the intervention intensity parameter  $a_p$ , we referred to online databases and literature, and combined with the actual situation of the country. In this section, we test the sensitivity of the model by changing the value of parameter  $a_p$ , to demonstrate its robustness.

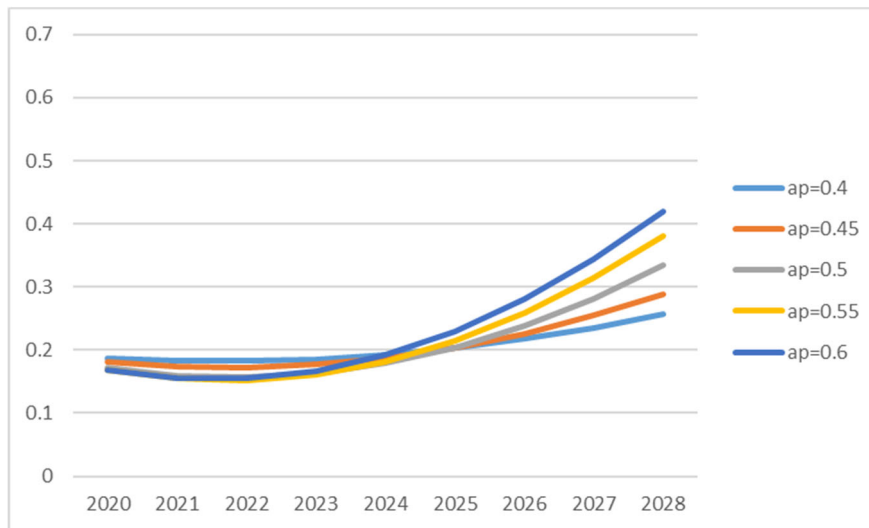


Figure 4. Sensitivity analysis

When analyzing Afghanistan, we set parameter  $a_p = 0.5$ , to show the intensity of the intervention. In Fig. 4, we change the value of  $a_p$  from 0.2 to 0.4, and find that the trend does not change significantly. So, we think our model is reliable.

## 5. Conclusion

### 5.1. Strengths and Weaknesses

1. When building the model, we used SPSS and MATLAB to preprocess and standardize massive data. Through a complex but meaningful set of pretreatments, the benefits of the food system in the economics, society, and environment could be reflected.

2. Our model has some flexibility. Through different weight calculation methods in Eq.16, we can evaluate the advantages and disadvantages of a food system from different aspects.

3. Our intervention model passed the sensitivity analysis and was robust. So, the implementation time of an optimal food system can be predicted for each country.

4. Our model cannot account for the effect of Covid-19. As it is still difficult to fully understand the potential damage caused by the Covid-19 pandemic, it should be recognized that

there are still significant uncertainties in the current assessment projections.

5. We didn't consider vegetarians, people with allergies, or individual differences such as gender and race. This can be improved by adding the regulatory factor of individual difference. Similarly, we don't consider the processing and packaging of the food. This can be improved by adding the regulatory factor of time lag to some relevant indicators.

### 5.2. Model Development

Due to the flexibility of indicators selection and weights calculation methods, our model has certain generalizability. Our model can be applied to smaller food systems, broader regions, and other biologically related mathematical problems.

Through this intervention model, we can simulate the growth curve of population and the intervention effect of corresponding policies on population.

## References

- [1] FAO, IFAD, UNICEF, WFP, WHO. In 2020. The State of Food Security and Nutrition in the World by 2020: Transforming the Food System and Securing Healthy, Economic Meals - Summary. Rome.
- [2] ZHANG J Q. The status of the food system in Japan and its research progress. Journal of Food Science and Technology, 2007, 26(2): 115-120.
- [3] GUO H, WANG L E, MA E P. The evolving concept of food system and a geographical paradigm of research[J]. Progress in Geography, 2019,38(07):1034-1044.
- [4] FAN S G, GAO H X. Rethinking the global food system under covid-19[J]. Journal of Huangzhong Agricultural University (Social Science Edition) ,2020(05):1-8+168.
- [5] LIU J J, LI B F, NING Y F, ZHANG W N. The concept, theory, and strategies of food urbanism[J]. Planners, 2012,28(03):91-95.
- [6] Databank. Retrieved from: <https://databank.shihang.org/home.aspx>
- [7] World Food Programme (WFP). Retrieved from: <http://www.wfp.org/>