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Towards A Sustainable and Equitable Food System

Summary

"Food is symbolic of love when words are inadequate." Alan D's words display the beauty of food. However, the environmental and equal problems caused by current food system are becoming increasingly rigorous. In this paper, a neotype food system covering production and distribution is developed to optimize for equity and sustainability.

Firstly, we approach production issue by constructing a **R**esources-**P**roductibility-**S**ustainability (**RPS**) model using publicly available data in order to account for the sustainability of our food system. Based on **IMPACT** method, we establish a baseline model through **regression analysis**, reflecting current production situation with the multiplication of agricultural resources and unit resource productibility. Using basic model as a foundation, then we apply **programming algorithm** and rearrange the agriculture resources for conventional crops, environmental-friendly crops and forests when sustainable factor is taken into consideration. Eventually, we obtain the RPS model after decent adjustments of productibility indexes.

As for the distribution link, we devise a novel **T**wo-dimensional **D**istribution **E**quity(**TDE**) plane model with **Comprehensive Distribution Entropy**(**CDE**) and **Fairness Degree**(**FD**) as coordinates. Given the complexity of actual food distribution system, we put forward the innovative concept of Comprehensive Distribution Entropy to display the active level and regional aggregation of food transportation process, thus representing the efficiency and partial equity of the general distribution system. Meanwhile, we combine **Entropy Weighted Method**(**EWM**) and **TOPSIS**, and calculate Fairness Degree from three aspects of economy, education and policy, estimating the equity level of a specific region. Additionally, we give the boundary values of two dimensions above through **K-means clustering algorithm** and divide the two-dimensional coordinate system into nine units representing nine states. In this way, we transform the abstract and complex distributive equity problem in real life into visual coordinate points in the geometrical two-dimensional plane. Finally, we systematically list the adjustment principles of government budget in transport road construction and public welfare according to the resulting coordinate points and priority target.

To verify the effectiveness of our models, we choose China and UK in our case studies and obtain 72.3% reduction in GHG emissions for developed countries and 26.3% for developing countries when food system prioritizes sustainability. Besides, the TDE plane model coordinates for China and UK are acquired as (Good, Dull) and (Excellent, Active) respectively. Furthermore, we calculate the benefits and costs of changing the food system' s priorities for both countries, and achieve the implentation time of 2060 in China and 2031 in UK with **auto-regressive algorithm**.

At last, we conduct a scalability and adaptability analysis and conclude the report via discussing the strengths and weaknesses of our proposed model.

Keywords: Food System; Comprehensive Distribution Entropy; TOPSIS; K-means Algorithm; Linear Programming

Contents

1 Introduction

1.1 Background

According to the estimates of The State of Food Security and Nutrition in the World, nearly 690 million people suffered from hunger in 2019, an increase of 10 million compared with 2018, and an increase of nearly 60 million compared with five years ago.[15] By the end of 2020, the COVID-19 pandemic may put 130 million people into a state of long-term hunger worldwide. [1] According to statistics on Wikipedia, so far, there will be more than 7.8 billion people worldwide in 2020. Although the current population growth rate is slowly decreasing, considering the huge world population base, how to meet the food demand of the continuously growing population is still a serious problem. The current food production can feed all human beings, but the imbalance of food production area and population distribution makes a large number of people in the world still in a state of food insecurity. [16]

In addition, the current food system focuses on efficiency and profitability, ignoring environmental damage. In terms of soil quality, the current planting industry relies too much on nitrogen and phosphate fertilizers, and long-term excessive and pure use of chemical fertilizers will make the soil acidified or alkalized. In terms of global climate, the continuous accumulation of the greenhouse effect has caused global warming, which also poses greater challenges to crop growth. Springmann et al. proposed that between 2010 and 2050, if there is no technological change and special mitigation measures, the environmental impact of the food system may increase by 50-90%, reaching beyond the planetary boundary[14] that defines the safe working space of humans. [2] Therefore, on the basis of the current food system, sustainable development is getting more and more attention. Taking into account the differences in the level of economic development, food supply and demand in various countries or regions, and the differences in purchasing power, the fairness of distribution is also an important issue[13].

In recent years, in order to enhance the stability of the existing food system, experts from diverse disciplines have made great efforts, but these systems are too complex to have good universality . [3]One thing for sure is that no matter which type of food system is, it is critical to have the ability to dynamically adjust the priority of the food system according to the current state and future development plans.

1.2 Problem Restatement

In this paper, we focus on the production and distribution in the food system, and discuss the impact and implementation time of changing system priorities. We need to solve the following problems:

1) Explain the changes after optimizing equity and sustainability and calculate the time for system state transition.

2) Calculate the time for changing the state of food system.

3) Verify the model separately in developing country and developed country.

4) Discuss the scalability and adaptability of the model.

1.3 Our Works

According to the requirements of ICM, we have developed a neotype food system that can optimize for various levels of efficiency, profitability, sustainability and priority. To strike a balance between sustainability (environment) and equality, our modeling activities will focus on building a Resource-Productibility-Sustainability(RPS) model and a Two-dimensional Distribution Equity (TDE) model to guide the production and distribution of the food system. The EDM model is designed to account for equity level, while the RPS model is designed to consider the sustainability of our food system,

To clarity, We define two production-distribution modes, one is "harmony mode", which prioritize sustainability and equity, and the other is "profit mode" that takes precedence over efficiency and profitability. The flow chart of this paper is shown in fig.5 as follows.

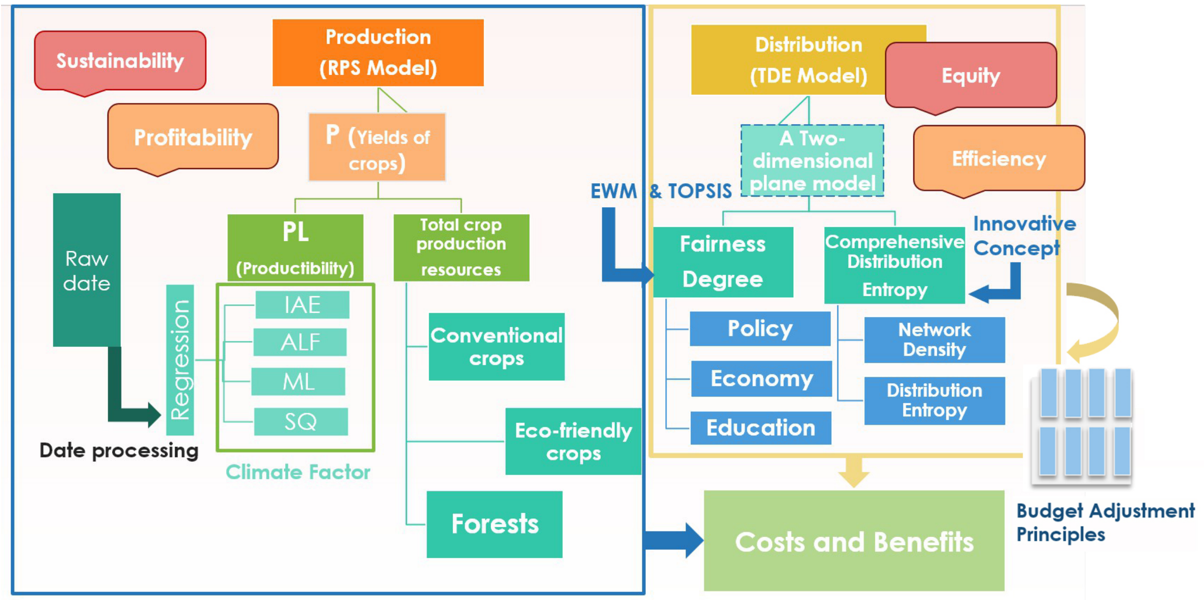


Figure 1: The Flow Chart in this Paper

2 General Assumptions and Notations

2.1 Assumptions

No matter what its scale is, Food system is complex and important. It involves many aspects, such as production, transportation, processing, distribution and waste disposal. At the same time, it is influenced by diverse factors like policy, economy, ecology. It's impossible and unnecessary to take all elements into consideration. So, we made a couple of assumption and simplifications, each of which is properly justified.

- We assume that there is no waste, all food is used for consumption and distribution.
- To simplify the model, our production model only considers the planting industry, not the animal industry.
- Based on the theory of **Perfect Competition** in economics, we believe that the output of agricultural products has nothing to do with prices.

- Output in the model is only related to production resources and productivity.

2.2 Notations

Notation that we use in the model are shown in the following table.

Table 1: Notations

Symbol	Description
P	The yields of crops
PL	Productivibility of unit production resource
S	Total crops production resources
S_E	Environmentally-friendly cropS production resources
S_C	Conventional crops production resources
S_F	Forest area
GHG	Greenhouse gases
r	The cost-benefit ratio
CF	Climate factor that effects the productivibility
GHG	Green-house gases
FD	Fairness degree
CDE	Comprehensive distribution entropy

3 Resources-Productibility-Sustainability(RPS) Model

In this section, we devise a RPS model, which is based on the production resources and the productibility of unit resources to guide crop production in different modes (Harmony mode and Profie mode). We first develop a RP baseline model to describe the production in the current food system through linear regression and parameter selection. Then we add the influence of environmental sustainability factors. Moreover, based on the programming algorithm, we get the final RPS model, which constitutes an essential part of production in the neotype food system.

3.1 Resources-Production(RP) Baseline Model

Inspired by Sherman Robinson's IMPACT model[4], in order to express the production more comprehensively, we calculate the production volume(P) by the multiplication of total production resource (S) and productivibility of unit production resource(PL), so we have

$$P = \sum_{i=1}^{n} S_i \times PL_i$$

whereS_i is the production resources of $i_t h$ crops, and PL_i is the unit production resource productivibility of S_i.

To calculate PL, we considered four indicators of irrigation application efficiency(IAE), agricultural labor rate(ALF), mechanization level (ML), soil quality(SQ). In addition, we also take the impact of climate conditions into account, so we have the following expression for PL:

$$PL = CF(\omega_1 IAE + \omega_2 ALF + \omega_3 SQ + \omega_4 ML)$$

1. Climate factor(CF): When considering climate's influence on PL, we refer to the formula of Hepburn,C. [Ref. 5] and select precipitation $Prunr$ to measure the overall climate level. Besides, we use the maximum change of precipitation$frac\ mathrmdPrunr\ mathrmdt$ during the period from t_0 to t_1 to consider the impact of extreme climate on productivibility. Therefore, we get the following formula:

$$EF_{t_o,t_f}(P_r) = P_r(t_f) + \lambda \max_{[t_0,t_f]} \left\{ \frac{\mathrm{d}P_r}{\mathrm{d}t} \right\}$$

Note that λ indicates the disaster index number brought about by climate.

2. Irrigation application efficiency(IAE):To compute the utilization rate of irrigation water, we choose the head-tail method [6]. The specific operation is to measure the water volume of all the water intakes that need to be measured during irrigation in the area ,i.e. the first value, and then use the field soil weighing method to calculate the amount of water that can be used by crops,i.e. the tail value. The ratio of tail value to head value is the accurate effective utilization coefficient of irrigation water. Multiple head and tail values will be added respectively and then we have:

$$IAE = \frac{m}{M} = \frac{\sum_1^i m_i + \sum_1^j m_j}{\sum_1^i W_i + \sum_1^j W_j}$$

In this formula, the sum of all the amount of water used by crops in the irrigated land area (m^3); W is the sum of all irrigation intakes in the area (m^3). According to the type of water source, it can be divided into i types of overground water irrigation areas and j types of underground water irrigation areas.

3. Agricultural labor rate(ALF): When calculating the agricultural labor rate, we take the number of rural surplus labor into our consideration, and use $h_1$and $h_2$to explain the resource allocation of labor force. If $h_1 = h_2$, the labor force has been allocated reasonably; if $h_1 \neq h_2$, the labor force has not reached the effective allocation, and there is surplus labor force in the economy; if $h_1 \geq h_2$, there is surplus labor in agriculture.Then we have:

$$ALF = (1 - \varphi)\frac{L_1}{L}$$

where $1 - \varphi = h_1 - h_2$, φ indicates the proportion of the essential agricultural labor force to the supply of agricultural labor forc; $1 - \varphi$ is the proportion of surplus labor force; L_1 represents the labor force allocated to agriculture, and L is the total labor force.

4. Soil quality(SQ):When evaluating soil quality, we employ Nemero index method [7] to calculate the comprehensive pollution index. The specific formula is as follows:

$$ML = 1 - \sqrt{\frac{K_{iave}^2 + K_{i\max}^2}{2}}$$

where K_iaveThe calculation average value of the pollution index of heavy metal elements in the soil of the survey site; K_imax is the largest single pollution index of heavy metal elements in soil.

5. Mechanization level(ML): We choose the power of tractors and modern power machinery to rackon ML. The ratio of the sum of the total power of modern tractors in dry and paddy

fields to the total power of tractors in this area is called the mechanical level of the system. In addition, a technological development factor is introduced to show that ML increases with the development of technology. Then we have:

$$SQ = h_t \times \frac{\sum H_{upland\ field} + \sum H_{paddy\ ield}}{\sum H}$$

where $\sum H_{upland\ field}$ refers to total power of tractors in dry land,$\sum H_{paddy\ field}$ refers to total power of tractors in paddy field,$\sum H$ denotes the total tractor, and h_t is the techonology development factor.

Finally, after obtaining the weights of S through the regression algorithm, we can get the production volume under the current food system.

3.2 Solution to RPS Model

In this section, we build a production model of our neotype food system, taking the goal of ecological sustainability into account. To sustain, even improve the health of our environment, we ought to take advantage of capability from two aspects. One is nature's self-recovery capability,i.e. the planting of forest. The other is human efforts, constructing of environmental-friendly agriculture system,i.e. the organic agriculture system, to reduce the pollution. Thus,we need to reschedule the proportion of forest (returning farmland to forest) and the proportion of environmentally-friendly crops within the limited production resources. We use linear programming algorithm to solve this problem, the detailed steps are given as follows.

3.2.1 Assumptions

a To simplify the calculation process, we use the arable land area to denote crop production resources

b We use the amount of greenhouse gases(GHG) released from different tillage patterns to indicate its degree of pollution to the environment.

c We will not expand arable land, all the solution is to re-plan the area of crops planted on the existing arable land.

3.2.2 The calculation of linear programming algrithm

Decision Variable:the conventional crops planting area proportionS_C;the environmentally-friendly crops planting area proportionS_E;forest area proportionS_F

- Characteristics of conventional agriculture mode: It is oriented to increase profits and yields. Most of the crops are planted with cereals, which have high profits and always release a large amount of carbon dioxide.
- Characteristics of environmentally-friendly agriculture mode: The planting is mostly fruit and sugar crops, and the profit and output are slightly lower than the conventional planting mode, but the amount of GHG released will be much less.
- Characteristics of forests mode: It has no monetary profit. The amount of greenhouse gas absorbed is used here to refer to forests' ability of remediating the environment.

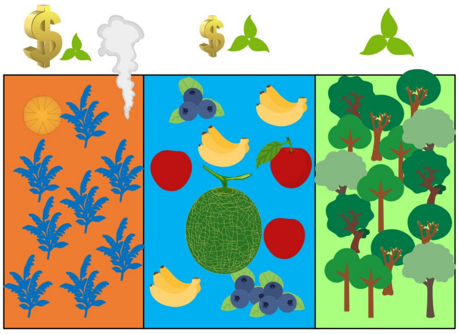


Figure 2: Three Planting Pattern Sketch

Minimize Levels In this part, We aim to minimize the total GHG emission(Z) of the planing area. In the first place, We display the complete programming formula as follows.

$$\begin{aligned} \min Z &= a_1 S_E + a_2 S_C + b S_F \\ s.t. S_E &\geq 0, S_C \geq 0, S_F \geq 0 \\ S_C + S_E + S_F &= 1 \\ S_C + 0.8 S_E &\geq LP \\ B_1 S_C + B_2 S_E &\geq \beta I_m \end{aligned}$$

Explanation

As for the objective function, b is he amount of carbon dioxide absorbed by forests per unit area; a_1 and a_2 give the amount of carbon dioxide released per unit area under the two agriculture mode, which can be reckoned by the multiplication of GHG intensity and yield per mu. For conventional crops, we choose the average value of GHG intensity of rice,wheat,nuts and oil crops to denote α_1 and the average of chosen fruits and suger crops to denote α_2 of environmentally-friendly crops. The details can be seen in the following figure.

Food item	Wheat	Rice	Nuts	Oil crops	Temperate fruits	Starchy fruits	Tropical fruits	Sugar crops
GHG intensity (kgCO2/kg)	0.23	1.18	0.71	0.46	0.08	0.11	0.09	0.02
Average	0.645				0.075			

Figure 3: The Name of Figure

As for the third constraint condition,LP is the minimum arable land area. As the yield of environmentally-friendly crops is on average 20% lower than that of conventional crops. Here we present the expression of LP, where POP is the population; EN is the essential personal energy.

$$LP = POP \cdot EN/PL$$

As for the forth constraint condition, B_1 and B_2 indicates the income per unit area of conventional crops and eco-friendly crops; I_m is the total economic benefits of the region. Meanwhile, we have$B_2 = 0.77B_1$[9]. β denotes the economic agricultural product export dependence index of the region; the reason for this restriction is that we consider that the economic development of some underdeveloped countries is based on a single agricultural product export dependence.

3. Final expression: After considering the division ratio of our production resources, the total regional output will be the sum of the output of environmentally friendly crops and the output of traditional crops.Then, the final production expression in our neotype food system is

$$P = P_E + P_C = S_E PL_E + S_C PL_C$$

Specially, we notice the decline in mechanization level PL_E because environmentally friendly agriculture emphasizes on crop rotation and natural pest control[9]. Therefore, we introduce u to display such change. The function is to be determined as follows:

$$PL_C = CF(\omega_1 IAE_c + \rho\omega_2 ALF_c + \omega_3 SQ_c + \omega_4 ML_c)$$

$$PL_E = CF(\omega_1 IAE_e + (1-\rho)\omega_2 ALF_e + \omega_3 SQ_e + u\omega_4 ML_e u)$$

ρ indicates the percentage of the number of people engaged in traditional crop cultivation in the total agricultural labor force.

4 TDE(Two-dimentional Distribution Equity) Model

In the distribution part of the new-type food system, we construct a two-dimensional plane model with fairness degree(FD) and comprehensive distribution entropy(CDE) as coordinates. The comprehensive distribution entropy is an innovative concept proposed by us. Fairness is analyzed from three dimensions of economy, education and policy by TOPSIS based on entropy weight method. Then, based on the K-means clustering algorithm, we divide the plane into nine units to help conduct budgetary allotment

we transform the abstract and complex distribution fairness problem into the visualized coordinate points in the two-dimensional plane of geometric mathematics, which helps to clearly determine the deficiencies in the current distribution system and subsequent goals. Thus, we can adjust the allocation of government budget in transport road construction and public welfare.

4.1 Calculation of Fairness Degree(FD)

4.1.1 Introduction of Index

According to the World Food Program, the hunger rate is not universal enough to evaluate the equity of a distribution system[10]. Therefore, we decided to consider three dimensions in fairness degree, namely, economic (ED), policy (EC) and education (PO). These three dimensions show that our consideration of fairness is not limited to the distribution of food, but also focuses on other aspects of society, such as gender equity and the income gap. Thus, we get the following formula:

$$EPD = \alpha_1 PO + \alpha_2 EC + \alpha_3 ED$$

where α_1, α_2 and α_3 denote the weights of policy, economy, and education in the evaluation.

Policy:

a **Gini:** Commonly used indicator to describe the gap between rich and poor in the system. Its easy calculation and clear definition are also the reasons for our selection.

b **Employment rate:** The level of employment rate reflects the rationality of social labor resource allocation.

c **Housing subsidy:** The existence of housing subsidies is to ensure the living standards of low-income groups. The amount and frequency of housing subsidies also intuitively reflect the degree of social assistance to low-income groups.

d **Public expenditure:** The payment of financial funds to provide public services and meet the common needs of society, which is set up to promote social equity.

Education:

a **Enrolment rate difference:** Our starting point is that compulsory education is universally socially fair, and a small difference in enrollment rates after this stage can represent that the system's educational resources are not subject to regional tilt.

b **Female education rate:** According to our research, if one area treats women more fairly, the area also has greater tolerance in other social equity [11] [12]. Therefore, we take gender equity into our considerations.

c **Proportion of rural teachers:** It reflects the degree of urban and rural education inclination. We believe that if the proportion of rural teachers is closer to 0.5, then urban and rural education is fair.

Economy:

a **Inequality of calorie intake:** This indicator is proposed based on the coefficient of variation of per capita calorie intake.

b **Protein supply difference:** The 2020 "State of Food Security and Nutrition in the World" report pointed out that the level of protein supply is important for the growth and development of children

c **GDP per capita:** GDP per capita fits the economic level well. We believe that regions or systems with higher GDP per capita are more capable of solving social equity issues.

Table 2: Indexes for Calculation of Fairness Degree

Target Layer	Dimension Layer	Indicator Layer	
Equity Degree	Policy	Gini	-
		Employment Rate	*
		Housing Subsidy	+
		Public Expenditure	+
	Education	Female Education Rate	*
		Proportion of Rural Teachers	*
		Enrolment Rate Difference	-
	Economy	Protein Supply Difference	-
		Inequality of Calorie Intake	-
		GDP per Capita	+

4.1.2 Weight Determination of Indexes

As for the weight of each indicator, we used the method of combined entropy weight method(EWM) and TOPSIS owing to the existence of uncertain indicators. Considering Analytic Hierarchy Process's intense subjectivity, we choose EWM to conduct the calculation.

As for equation of EPD, we have:

$$PO = \sum_{i=1}^{4} \beta PO_i$$

$$EC = \sum_{i=1}^{3} \gamma EC_i$$

$$ED = \sum_{i=1}^{3} \eta ED_i$$

Next we give the steps of combined EMW and TOPSIS.

Step I List the original matrix and weight matrix as follows:

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix}$$

where X_{ij} refers to the value of the j^{th} evaluation index for the i^{th} sample.

Then we calculate the proportion p^{ij} of the j^{th} indicator of the i^{th} sample.

$$p_{ij} = \frac{v_{ij}}{\sum_{i=1}^{n} v_{ij}}, 0 \le p_{ij} \le 1$$

Step II Get the Entropy Value E of the j^{th} indicator as below:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \ln p_{ij}$$

where $k = 1/\ln m$,$k > 0$

After getting the information redundancy value d_j by $d_j = 1 - e_j$, we can assign weights according to the degree of difference of each indicator's mark value, and acquire the corresponding weight of each indicator as follows:

$$w_j = \frac{d_j}{\sum_{j=1}^{p} d_j}$$

Step III Normalize the raw data:

$$z_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

Finally,we have the weighted matrix:

$$Z^* = \begin{bmatrix} z_{11}\cdot\omega_1 & z_{12}\cdot\omega_2 & \cdots & z_{1p}\cdot\omega_p \\ zz_{21}\cdot\omega_1 & z_{22}\cdot\omega_2 & \cdots & z_{2p}\cdot\omega_p \\ \cdots & \cdots & \ddots & \vdots \\ z_{n1}\cdot\omega_1 & z_{n2}\cdot\omega_2 & \cdots & z_{np}\cdot\omega_p \end{bmatrix}$$

Step IV Determine the ideal and negative ideal solutions z^+ and z^-:

$$z^+ = \max(z_1^+, z_2^+, \cdots, z_p^+)$$

$$z^- = \max(z_1^-, z_2^-, \cdots, z_p^-)$$

Step V: Calculate the separation measure from the ideal and the negative ideal solutions, D_i^+ and D_i^-, respectively, for the group:

$$D_i^+ = \sqrt{\sum_j (z_{ij} - z_j^+)^2}$$

$$D_i^- = \sqrt{\sum_j (z_{ij} - z_j^-)^2}$$

Calculate the relative closeness to the ideal solution and rank the alternatives in descendin-gorder. The relative closeness of the i_th alternative, with respect to positive idea solutioncan be expressed as

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}$$

where $0 \leq C_i \leq 1$. The larger the index value, the better the performance of the alternative.

4.2 Comprehensive Distribution Entropy(CDE)

4.2.1 Assumptions

1 To clarify, we use the funds lost in the transportation process to describe the tendency of the system to transport grain.

2 We believe that the total loss of funds in the system tends to decrease.

3 We ignore other modes of transport other than railways, roads and inland navigation, because they have little impact on the transport capacity of the system.

4.2.2 The Explanation of CDE

We creatively introduce the concept of comprehensive distribution entropy to describe the active level of the transportation system in a certain area. Since this is and innovative concept, we will explain the meaning of distributive entropy from the following three aspects:

- **Basic meaning**: The basic freight status of the road transport system. It shows the density of goods flows in the whole system and is a dispersion index of the transport volume per unit time in a system. It has nothing to do with the point-to-point transportation in the region and breaks away from the limitations of the food supply chain from the place of production to the place of demand, but is related to the activity and load of the whole system transporting goods.

- **Economic meaning**: Economic benefits in the process of goods transportation. It not only shows the freight volume per unit transport section of the whole system, but also characterizes the transport loss. In order to maximize economic benefits, we need to weigh freight volume and transport loss. If the freight volume increases, the transport loss will also increase, but the total monetary benefits will not necessarily increase. Therefore, the economic benefit is actually a dual function of freight volume and transport loss.

  The formula for calculating the loss of funds during the transportation of the whole system is given in the following formula:

  $$W_{loss} = S \cdot c \cdot \beta_c \cdot_d \cdot M_d \cdot u$$

  where S is the distribution entropy, A is the total area of the system, c is the transportation cost per unit mass per distance, β_c is the proportion of grain in the goods, M_d is the grain quality transported, and u is the transportation loss rate.

- **Market meaning**: As we mentioned in the hypothesis, when the loss of funds in the transportation process becomes smaller, and the region will tilt the market to the areas where the transportation loss is small, which is in line with the basic principles of the market. The smaller the total loss fund is, the more part of the system is gathered, with some areas closely related, which does not meet our requirements for fair distribution of the system in the harmonious mode.

4.2.3 The Calculation of CDE

To calculate CDE, we need to figure out Distribution Entropy(DE) first. Emulating the definition of entropy in physics, which is $S = \ln P$, we give the definition formula of DE:

$$S = \ln \zeta, S > 0$$

where ζ refers to the activity index, relating to the cargo in circulation in unit mileage.

We choose three main aspects of the transportion system to represent ζ: highway transportation, railway transportation and inland waterway transportation.

$$\zeta = c_1\zeta_h + c_2\zeta_r + c_3\zeta_i$$

where $\zeta_h, \zeta_r, \zeta_i$ denotes hightway, railway, inland waterway's activity index respectively, which can be obtained by dividing the corresponding freight volume by mileage. c_1, c_2, c_3 denotes their contribution to total index.

Considering that there will be traffic congestion on highways compared with railways and inland waterways, we take a normal distribution model to express its congestion, and the improved formula is as follows:

$$\zeta = c_1\zeta_h e^{\left|\frac{\theta-\theta_0}{-2k^2}\right|} + c_2\zeta_r + c_3\zeta_i$$

To be more frankly, θ is the highway traffic index, also known as traffic congestion index or traffic operation index–a conceptual index value that comprehensively reflects the smooth flow or congestion of the road network. θ_0 represents the highway index when the highway transportation efficiency of the system is the highest, k is a constant and is used for normalization.

Eventually, we make our way to CDE. In order to take the transport capacity of the system into consideration, the comprehensive distribution entropy(CDE) $\mathbb{S}$ is introduced to show the transport status and capacity of the system comprehensively.

$$\mathbb{S} = S \times \rho$$

ρ refers to the road network density, which can be achieved by the expression

$$\rho = \sum_{i=1}^{3} \frac{L_i}{A_i} = \rho_{ground} + \rho_{aviation}$$

L_i represents the mileage of the $i_t h$ mode of transportation, and A_i represents the total area of the system.

The concept of CED is established based on the specific traffic infrastructure of the region. In other words, if the distribution entropy is regarded as a coefficient, the comprehensive distribution entropy can also be regarded as the transport function of the active part of the road network density.

4.3 Working Principle of Two-dimensional Distribution Equation Model

4.3.1 Basic Concept

First of all, we calculate the scores of fairness degree and CDE of 169 countries according to the indicators considered. Moreover, we use the K-means clustering method ($K = 3$) to do cluster analysis of fairness and comprehensive distribution entropy respectively, and then get three levels of evaluation. As for the fairness degree,the three evaluation levels are excellent (E), good (G), bad (B). Meanwhile, their boundary value is shown in the following figure.

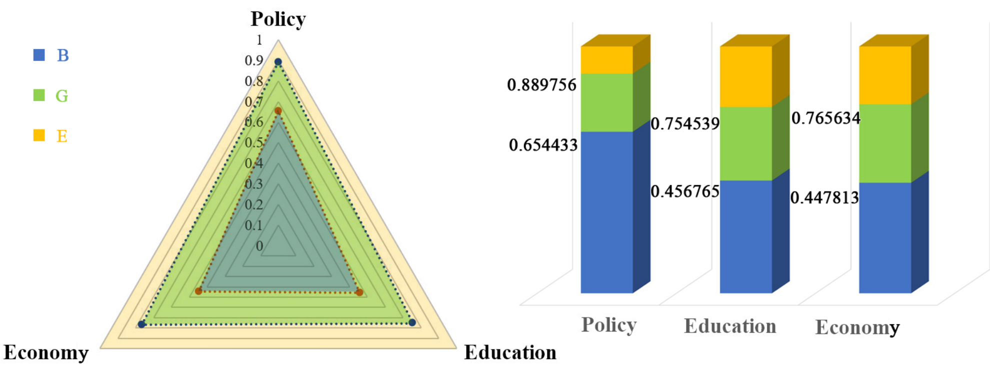


Figure 4: Results of FD by K-means

We also exhibite have the three evalution levels as active(A),normal(N) and dull (D).

4.3.2 Assumptions

1. We believe that the transition from one state to another is completed when it crosses the boundary between the two.
2. In order to simplify the model, we take the time needed for the state transition as the time for the construction of the transportation system to reach a specific CDE.
3. The level of the target state must be higher than the current state.

4.3.3 Operating Principle Of Two-dimensional Distribution Equity Model

We use the above calculated FD and CDE as the ordinate and abscissa of the final two-dimensional plane respectively. In addition, given the boundary values above, the two-dimensional plane is divided into nine units (fig5), named as (E,A),(E,N),(E,D),(G,A),(G,N),(G,D),(B,A),(B,N),(B,D). Therefore, we can use the scores of the system in these two dimensions to locate in the coordinate system and determine the state of the current food system allocation. We believe that if the priority of the system is adjusted, the scores of fairness and comprehensive

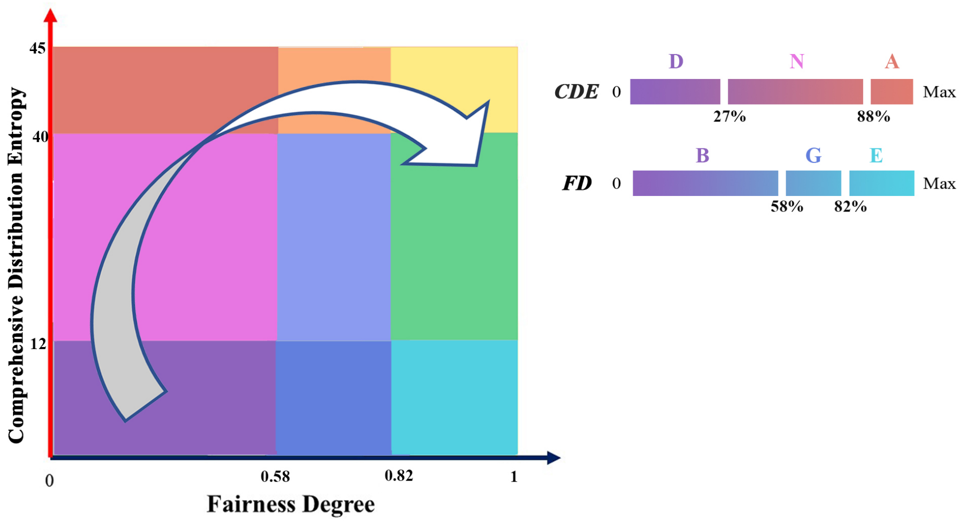


Figure 5: Two-dimensional Distribution Equity Model

distribution entropy will be affected, and when its coordinates cross the boundary line, we think that the distribution state of the system has changed. that is, the new state becomes the current state, ignoring those on the boundary. If there are new measures to intervene, then the system will jump from the current updated state to the next new state. For simplicity, we define time as considering the completion time of system changes caused by current measures, that is, if the system is set to reach a certain state, then the transition time should be the sum of the time across the state on its path.

In order to systematically describe the guiding role of our two-dimensional model, we give the following budget adjustment principles:

- When the goal of one dimension of the two-dimensional coordinates is to increase the level by two levels, then increase the budget of that dimension by 50 percent.

- When the goal of one dimension of the two-dimensional coordinates is to increase the level by one, then increase the budget of that dimension by 30 percent.
- When the goals of the two dimensions are the same, the budget for transport roads construction and public welfare should be adjusted to the same level simultaneously.

5 Calculation of Costs and Benefits

In this section, we aim to figure out the benefits and costs of changing the priorities of a food system, which are closely related to the comprehensive distribution entropy. Hence, We take the specific costs and benefits of the transportation system as our ultimate goal. Notably, we consider the construction and operation of the transportation system separately, taking the ecological cost as the operating cost of the system.

Table 3: Overview of Variables Considered for Cost-Benefit Ratio Model

Variables	Units	Justification
Employee Compensation	Current US $	The wages of workers in the construction of the transportation system and the expenses to pay for increased wages of agricultural workers engaged in environmentally friendly crops.
Technology Input	Current US $	Technical costs involve developing new varieties with high yield and improving soil quality.
Raw Material	Current US $	The cost of lime, cement and other raw materials used in the reconstruction and expansion of the transportation system.
Environmental Degradation Cost	Current US $	Refers to the various damages caused by pollutants discharged in the process of construction projects, which are reflected during operation.
Pollution Treatment Cost	Current US $	Indicates the cost of various pollution treatments that we consider to solve the environmental pollution of the project during the operation period.
Agricultural Income	Current US $	Agricultural income for the development of agricultural product sales channels and the acceleration of agricultural product distribution efficiency.
Transportation Social Benefit	Current US $	The social benefits brought by the movement of people and the transportation of non-agricultural goods.

5.1 Costs

Our transportation system costs consists of constructions costs and perating costs.When calculating construction costs, we introduce the concept of cash flow, which is calculated through expected cash flow, present value factor and discount rate. Therefor we finally get a more realistic construction cost by considering the impact of construction time instead of simply adding up all costs:

$$C_1 = \sum_{i=1}^{t_1} \frac{w_i + k_i + T_i + C_{con,i}}{(1+r)^{t_1}}$$

Where, C_1 is the cost in construction time; t_1 is the construction period, r is discount rate; E_i, T_i, R_i, are respectively the employee compensation, technology input and raw material cost in year i.

When calculating operation costs, which is ecological costs actually, we also introduce the concept of cash flow, since the capital investment in the operation phase is time-related. The cost during operation time can be obtained as follows:

$$C_2 = \sum_{i=1}^{t_2} \frac{m_j + d_j}{(1+r)^{t_2}}$$

Where, C_2 is the cost during oprating time, t_2 is the opration period, r is discount rate, m_j, d_j are respectively the environmental degradation cost and pollution treatment cost in year i.

5.2 Benefits

We do not consider the introduction of cash flow in benefit, since the growth of agricultural income and transportation benefit is not significantly correlated with time. If the constructed transportation system is put into use, we can continuously get agricultural benefits and transportation social benefits. So the benefits of the transportation system is:

$$I = I_a + I_t$$

Where, I_a is agricultural benefit and I_t is transportation benefit.

Finally, the cost-benefit ratio(r) is

$$r = \frac{C_1 + C_2}{I_a + I_t}$$

6 Validating the Models

6.1 TASK1: Optimization for Sustainability and Equity

6.1.1 Optimization for Sustainability in Food Production System

We have developed a Goal Programming model to optimize the food production model for sustainability, within the acceptable range of profit changes. In this case, the difference in economic effects between traditional crops and eco-friendly crops is one of the most significant factors that influences the profitability of the food system. Therefore, even if eco-friendly crops give lower profits, they are still worthwhile for active functions in improving soil fertility and controlling weeds.

Results

To optimize for sustainability, we need to increase the arable area of eco-friendly crops and the forest area under the limitations of profitability. When Sc : Se : Sf is equal to 0.671 : 0.124 : 0.205, the sustainability is optimal. At this ratio, the profitability of the system is slightly reduced, decreasing to 92.14% of the original system, which is not significant. Although it is difficult to further improve the profit, we believe that the economic and ecological benefits will increase rapidly together, with the continually upgrading and developing of our eco-friendly model.

Other Factors

1) **Technology Development**

The sea rice cultivated by the hybridization technology can grow in saline-alkali soil with a salinity concentration of more than 0.3% and the yield of 300 kg/667 m2.[17] The emergence of these new varieties expands the potential arable area and brings benefits to farmers, however, without excessive ecological cost.

2) **Increase in Effective Planting Area**

At present, the proportion of irrigation water and fertilization in farmland is adjusted according to experience, easily leading to water runoff, soil erosion and nutrient loss. If the ratio of irrigation water to fertilization based on the soil quality and the local water flow network can be pre-calculation, the efficiency and benefit of planting areas will increase.

Other systems

We calculated the sustainability level and profitability of several existing food systems, such as the local food system. We found it profit high for the constrained transportation cost, while easy to be saturated in the local market. In addition, Bohn et al. proposed that this system is easy to fall into a “local” trap, and it is not more sustainable than other scale food systems.[18] Our calculations support this. If the local food system considers sustainability optimization, its profitability will be reduced to 72.31% of the original, which is significant.

6.1.2 Optimization for Equity in Food Distribution System

Since policy has the greatest weight on the fairness, we choose the public fiscal expenditure budget to optimize the equity of the system. Here we use a thought experiment to illustrate the workflow of the distribution model. A certain system is rated as (P, N), which means that it has poor equity and normal allocation activity. To increase the PD by two levels, the budget for people’s livelihood and welfare should increase by 30%. Calculating the FD and CDE scores, we get (G, N), which shows that the increase in FD is relatively larger, reaching 30%, while the CDE decreases slightly, as the cost of transport maintenance has been reduced. However, the reduction is not large since the transport system can still work well.

6.2 TASK2: Analysis of Benefits and Costs

Profit Mode in Land Planning

Before changing the priorities, the food producers tend to grow traditional crops to grow for profit. In this case, the release of GHG is 1180kg.

Harmony Mode in Land Planning

By this mode, the proportion of eco-friendly crops and forest will increase. We choose 6 countries (developed: the United States, the United Kingdom, Denmark; developing: Zambia, Angola, Zimbabwe) to calculate the average, representing the land planning of the developed and developing countries with harmony mode.

From above, we get Sc : Se : Sf is 0.11:0.52:0.37 in developed countries,while 0.69:0.28:0.03 in developing countries. Developed countries have 24% more eco-friendly crops, 34% more forest cover, while 58% less traditional crop. The GHG emissions in developed and developing countries are 326.5 kg per mu and 870 kg per mu, respectively.

We select the cost-benefit ratio in 2019 as the start point of estimation, noting that it is 0.51 for developed countries and 0.32 for developing countries. The cost-benefit ratio of developed

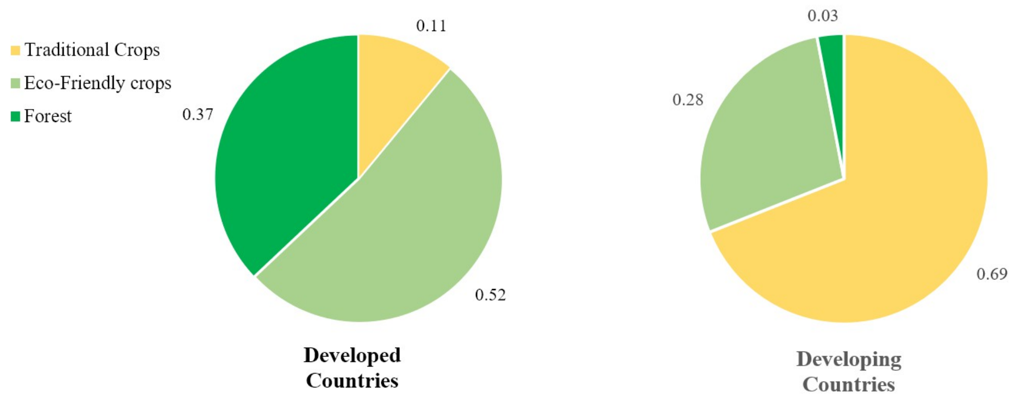


Figure 6: Harmony Mode in Land Planning of Developed and Developing Countries

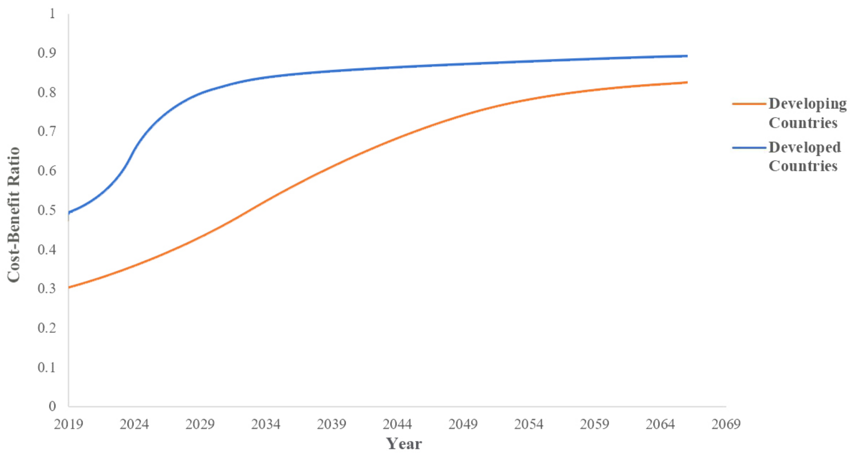


Figure 7: Cost-Benefit Ratio of Developed and Developing Countries over Time

countries is expected to reach of 0.8 in 2031, while developing countries in 2060 at a slower growth rate.

According to the formula of the minimum arable land area, developed countries have high productivity per unit of resource and low population density, thus feeding more people with less arable land area. In developing countries, on the contrary, the necessary minimum arable land area is larger, and the proportion of the planting area reserved for traditional crops is correspondingly expanded. For instance, many African countries can only rely on plantation economies, export a single agricultural product to support their economies, so their production optimization is low.[19]

6.3 TASK3: Case Study on China and UK

We use case study on China and UK to validate our models.

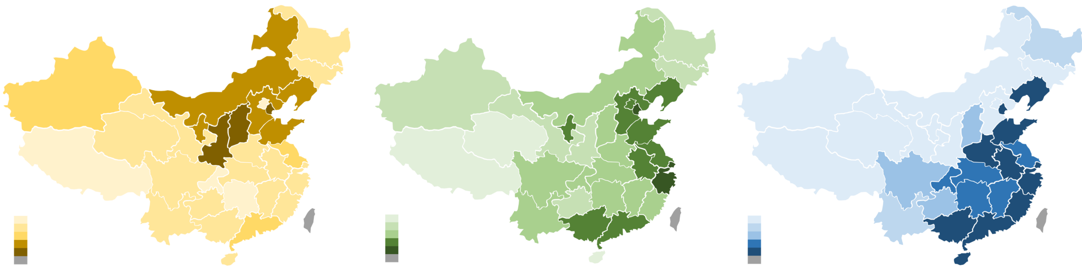
- **Calculate the Network Density**

  We take China's land area as 9.6406 million square kilometers, and get the network density, which is 0.54996875 (10000 km / 10000 km^2).

- **Calculate the Distribution Entropy (DE)**

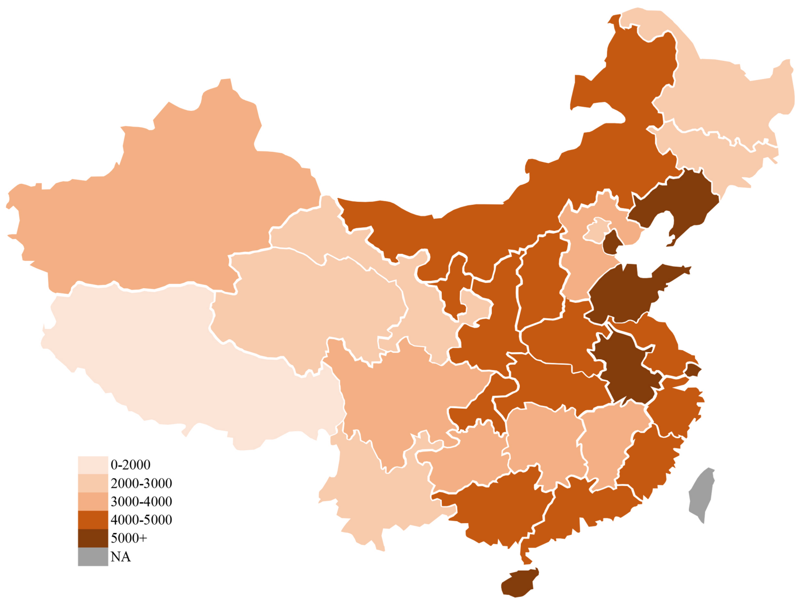
- **Calculate the Distribution Entropy (CDE)**

  We sum the distribution entropy of each province and multiply it by the network density, and get the China' s comprehensive distribution entropy (CDE) is 6.945295, which is rated as **DULL (D)**.



(A) Rail (B) Road (C) Inland Waterway

Figure 8: Partial DE for Rail, Road, Inland Waterway Transport in China's provinces in 2019



Data per Province

Province	Distribution Entropy*10^3
Anhui	5442.67
Beijing	2531.75
Chongqing	4050.23
Fujian	4951.08
Gansu	2644.11
Guangdong	4732.59
Guangxi	4348.37
Guizhou	3058.61
Hainan	5696.93
Hebei	3737.70
Heilongjiang	2998.45
Henan	4916.35
Hubei	4048.85
Hunan	3408.69
Jiangsu	4152.85
Jiangxi	3486.52
Jilin	2662.29
Liaoning	5776.03
Neimenggu	4101.50
Ningxia	4052.61
Qinghai	2636.62
Shaanxi	4879.64
Shandong	5260.82
Shanghai	5904.61
Shanxi	4402.55
Sichuan	3182.57
Taiwan	NA
Tianjin	6948.88
Xizang	6.64
Xinjiang	3161.72
Yunnan	2827.05
Zhejiang	4866.71

Figure 9: Distribution Entropy (*10^3) in China's provinces in 2019

Similarly, we calculated that the network density (NE) in the United Kingdom is 3.61746975 (taking the area of the United Kingdom as 244,100 square kilometers). Its distribution entropy (DE) is 11.749233, and its comprehensive distribution entropy (CDE) is 42.50249501, which is rated as **ACTIVE (A)**.

The fairness degree of the two country are also showed.

China is rated as **GOOD (G)** in terms of FD, and the United Kingdom is rated as **EXCELLENT (E)**. In summary, the status of China is **(G, D)** and the status of UK is **(E, A)**.

Table 4: Fairness Degree of China and UK

	Policy	Education	Economy	Fairness Degree
China	0.859517313	0.782081536	0.749431795	0.797010215
United Kingdom	0.919322244	0.786510283	0.87424535	0.860025959

China's score rating on the CDE is **POOR**, and we explain the result as follows:

- China has the third largest land area in the world, while the difference of geographical and economic development is significant between regions. From the heat map, the distribution entropy of the eastern coastal provinces is generally high, especially in Shandong, Jiangsu, and Liaoning, which have high proportion of maritime transport and high level of economic development. As for the western regions, their population is sparsely populated, and the terrain is complicated, not to mention the inland waterway. Therefore, the overall entropy is small.
- UK's land area is 2.5% of China' s, and its distance that needs to be crossed for transportation is less than that of China. At the same time, the United Kingdom is an old-brand developed country in the world and the first country to invent the train. Its industrial development and transportation system construction are advanced in average. The road network density in the UK is 1.616 km/km^2, which can well prove the points above.

There is little difference between the FD of China and UK, only eight percentage points, but the ratings are not the same. China still needs to increase three percentage points to reach an excellent state. We believe that China is still limited by the current economic development and cannot support the improvement of the welfare system. Meanwhile, it has a long way to go in the transportation system. We suggest that China can gradually increase the public fiscal expenditure budget for people's welfare and construct a more efficient transportation network.

6.4 TASK4: Discussion of the Scalability and Adaptability

In our system, the indicators we consider are universal without focusing on a certain country or region. For example, the policy dimensions we consider in the distribution model can be interpreted as regional policies or national policies. The public fiscal expenditure can be interpreted as either regional fiscal expenditure or national fiscal expenditure. In the production model, we also put forward some common indicators, such as the number of laborers, which is abstract. When we apply the production model to a region, we can count the number of laborers in the region. For a country, we just need to count the number of laborers in that country.

Meanwhile, we convert some indicators with factors that are easy to handle, but still representative. For example, when we deal with ecological factor, we express it as precipitation, whose data are easy to obtain and operate. and the precipitation can reflect the climate environment well.

Therefore, reviewing the production model and distribution model, we are confident that our system is highly scalable and adaptable.

7 Sensitivity Analysis

RP Baseline Model

Regardness of different types of crops, PL is directly related to total grain production per unit of time. Using partial least squares (PLS) regression, We have counted china's data over the past ten years, and determined the weights of the four indicators affecting PL.

$$\frac{PL}{EF} = 171.6631 + 158.6918IEW - 0.0005240ALF - 0.29522SQ + 2.5782ML$$

Introduced a percentage error into the model ranging from 1% to 10%, the value floating as follows[**?**].

Table 5: Sensitivity Analysis of RP Baseline Model

	IEW	ALF	SQ	ML
1%	0.90551%	0.00000%	-0.00168%	0.01471%
2%	1.81103%	-0.00001%	-0.00337%	0.02942%
5%	4.52757%	-0.00001%	-0.00842%	0.07356%
10%	9.05515%	-0.00003%	-0.01685%	0.14712%

IEW is the most significant indicator functioning when biased, while ALF is much more weaker with the result in the model.

TDE Model

- **Distribution Entropy**
  The calculation of distribution entropy is robust, as the load and load limit of rail, road and inland waterways are almost constant at different times in the same system. When the rail freight is 5% off, the deviation of distribution entropy is less than 0.00001%.
- **Comprehensive Distribution Entropy**
  Considering the network density, CDE is much more differ among systems. However, because of the certainty of transport lengths and land area, the network density has been changing slowly in periods, and insensitive to emergencies and socio-economic changes.

8 Strengths and weaknesses

8.1 Strengths

1) We propose a geometric model to visualize the state of the distribution part of our food system, projecting complex problems abstractly onto a two-dimensional plane, and complete the transformation between different states of the system by taking hierarchical measures.

2) We creatively put forward the concept of comprehensive distribution entropy to reflect the activity and regional aggregation of the grain transportation process, which allows us to balance between efficiency and fairness.

3) The consideration of indicators is comprehensive and objective. We have considered enough indicators in the production and distribution models, as well as the cost-benefit ratio model, and they have been rationally analyzed.

4) Our model is flexible and feasible. Through specific analysis of local economy, policy, and education, we give representative indicators in the Fairness Degree model, so the obtained results are significantly reliable.

8.2 Weakness

1) Although we have tried our best to find data for some indicators, we have not been able to find enough data. As a result, the missing data will affect the accuracy of the calculation.

2) We propose distinct assumptions for various models mentioned in our paper. However, as food systems are complex and region-based, the assumptions we make may not be thoughtful and considerate enough to accout for every detail of our actual world.

9 Conclusion

In this paper, a neotype food system that can be adjusted to various levels of harmony mode and profit model is constructed. RPE model accounts for the sustainability of production process while TDE model for the equity of distribution. We implement these two models to China and UK separately and analyze the differences of the two. Results of GHG emission amount and coordinates points are in is consistent with the reality. Combining the results of scalability and sensitivity analysis, our models are reliable and feasible.

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