Stability Evaluation and Optimization of Food System Using PEFS Mathematical Model and Big Data Technology

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Abstract. Today in our world, the food system is very unstable despite its high efficiency and profitability. More and more problems and even tragedies are caused by the instability of today’s food system. Therefore, the stability evaluation and optimization of the food system need to be implemented as soon as possible. A basic model named PEFS is established for better understandings of our global food system based on the mechanism analysis of the food supply chain. Its output is the efficiency and profitability of any food system. We can use the PEFS model to simulate the global food system. Relying on the collected data, the model gives the profitability and efficiency of food systems in 162 countries around the world. The visualized map is shown in Figure 4. Among them, Guatemala is the country with the highest profitability, reached 0.812. Argentina is the country with the highest efficiency, reached 0.854.

1. Introduction

1.1. Problem Background

The increasing world population, coupled with resource and environmental pressures, bringing huge challenges to food security. More than 800 million people in the world endure the pain and harm of hunger and malnutrition. Even if enough food was produced, the food was wasted and inappropriately distributed due to unconscionable processing, transportation, and distribution. In rich countries, there are also food insecure people and areas of food scarcity, those are nutritionally imbalanced and even unable to obtain water and enough food. Meantime, inefficient and extensive food production methods not only cause waste of manpower and material resources, but also pollute the environment and intensify climate warming.

Food system is a huge network system describing the production, sales and distribution of food in a region. The food system not merely includes food and consumer, it’s also affected by drives, such as marketing services, policy support, and technical updates, which sustain daily operations and continuous optimization of the system.
1.2. Restatement of the Problem

Today's food system needs to efficiently produce enough food, pay attention to the equitable distribution. Additionally, the sustainability of the environment and resources must be taken into account. To optimize the current food system, we need to solve:

- The constituents, drives and priorities in food system;
- The results of optimizing food system with fairness and sustainability, the difference between the current and the optimized food system, and the time required to complete the optimization;
- The costs and benefits of changing food system priorities, and in which cases does it happen? What is distinguished when changing the priorities of food systems between developed and developing countries? Give at least one example for countries with different levels of development;
- Discuss the optimal food system scalability and adaptability.

2. PEFS (Profitability & Efficiency Food System) Model

PEFS model (Profitability & Efficiency Food System Model) is the basic model for our entire article. The model starts with the supply chain of the food system, and a food system that only focuses on efficiency and profitability was built by analyzing the relationship of the supply chain from production to processing and effective utilization. When the specific input values of the PEFS model are given, the model can quantify the efficiency and profitability of a food system. The composition of the model are as follows:

![Figure 2. The composition of the model.](image-url)
2.1. Model Building Based on the Food Supply Chain

By analyzing the relationship between the various links of food supply chain in Figure 3, we build a PEFS model with the efficiency and profitability of the food system as the output value. The construction method are as below:

2.1.1. The efficiency.

In the Production link, the production efficiency of the ecosystem was defined as:

$$\eta_1 = f_1 \left( \frac{TO}{TT} \right)$$

(1)

Where $f_1(\cdot)$ is an increasing function with a value range of $(0, 1)$.

Combined with Hypothesis 1, the operating efficiency of the ecosystem after the production stage can be calculated across the entire food supply chain

$$\eta_2 = f_2 \left( \frac{\delta_1 + \delta_3 + \delta_2}{EU - \gamma_1 \times FR} \right), \in (0,1)$$

(2)

Where $f_2(\cdot)$ is a decreasing function in the range $(0, 1)$.

Where $FR$:

$$FR = TO \times \lambda_1 + (1 - \lambda_2) \times TO + (1 - \lambda_2) \times (1 - \lambda_3) \times TO$$

$$= P(\lambda_1, \lambda_2, \lambda_3) \times TO$$

(3)

So the total efficiency of food system can be defined as:

$$\eta = \frac{\eta_1 + \eta_2}{2}$$

(4)

2.1.2. The Profitability.

Through the analysis of the mechanism between input, loss and residue in the food supply process in Figure 3, the right calculation formula was obtained as follows:

$$w = \frac{TO - (\delta_1 + \delta_2 + \delta_3) - FR \times (1 - r) + FR \times r - TI}{TO}$$

(5)

2.2. Parameter Estimation

2.2.1. Estimation of $\lambda$.

1. From the literature[5], the residual rate in gross and food production $\lambda_1 + \lambda_2$, in transportation $\lambda_2$, in processing $\lambda_3$ were obtained:

| Table 1. Residual Rate in Food Supply Chain. |
|---------------------------------------------|
| $\lambda_1$ | $\lambda_2$ | $\lambda_3$ |
| 2.385% | 9.238% | 12.073% | 32.917% |

Where, the average of $\lambda_1, \lambda_2$ is the estimate of $\lambda$.

2.2.2. Estimation of $r$.

As for recycle rate $r$, according to Aiello's statistics, the recycle rate of residual food from suppliers, manufacturers and wholesalers is 10.9%, 35.3%, and 35%. It is prevalent for non-
profit organizations and food banks to recycled food at a recycling rate of only 4.6%. Therefore, the weights are 0.3 and 0.7 for these two methods respectively. The recovery rate obtained:

\[
r = 0.3 \left( \frac{r_1 + r_2 + r_3}{3} \right) + 0.7 r_2 = 11.34 \%
\]

2.2.3. Estimation of $T_I$, $T_O$ and $\delta_i$. We have collected some indicators and data on the database and website to estimate the four parameters. It contains indicator data for nearly 160 countries. After processing the data (the data processing is given in 5.1), we use the existing indicators and data measuring the parameter values in each country’s food system.

For the food system of any country, the parameters estimated in the above way acted as input into the PEFS model. The efficiency and profitability of each food system can be obtained when only these measurements are considered in the food system.

2.3. Results

According to the data we have collected from 162 countries, all the input parameters was estimated and input them into the PEFS model to get the profitability and efficiency of the food system corresponding to these 162 countries. Due to the large number of countries, the results after visualization are given as figure:

![Figure 3. The profitability (above) and the efficiency (down)](image)

3. Stability Index of Food System

The PEFS model we have established reflects to a certain extent of the status of the food system in the world today, which is, giving priority to efficiency and profitability. Nevertheless, this food system is unstable. The environment is destroyed, energy is gradually scarce, and some people die of hunger. Therefore, the establishment of a more stable food system is particularly important, but before that, we must figure out what "Stability" is.
Figure 4. What’s the stability?

Combined with the description of the topic, our team believes that a stable food system needs to consider profitability, efficiency, sustainability and fairness at the same time. Based on this thinking, we established a stability index to evaluate the stability of a food system. And such an evaluation model requires the support of data and indicators, the indicators, data and processing we collected was given in 5.1.

3.1. The Data and Indicators

3.1.1. Data Collection. We have collected the values of 27 indicators in 162 countries around the world over the past 20 years. Even if it is downloaded from the latest data set, the indicators we have collected are missing data in year and country. We deleted countries with a data missing rate of more than 60%, and used interpolation to fill in other missing data, we finally compiled data for 162 countries. The database sources we collected are:

Table 2. Data source collection.

| Database Names       | Database Websites                                      | Data Type  |
|----------------------|--------------------------------------------------------|------------|
| WHO                  | https://apps.who.int/iris/handle/10665/338902          | Health     |
| World Bank           | www.worldbank.org                                       | Economic   |
| FAO                  | http://www.fao.org/statistics/en/                       | Agricultural |
| IFPRI                | https://www.ifpri.org/                                  | Agricultural |
| CAIT                 | CAIT: Creative Arts and Integrated Therapies            | Environmental |
| CAIT (caitresearchgroup.com) |                                                      |            |
| Food System Dashboard| foodsystemsdashboard.org.                               | Comprehensive |

3.1.2. Indicators Classifications. We collected some relevant indicators that can measure the profitability, efficiency level, and sustainability of the food system. Different indicators are used to measure different attributes. The specific components are given in the figure. These indicators may not directly reflect the corresponding capabilities, but they do have a certain correlation. We give the calculation process based on these indicators in 5.2.1.
3.1.3. Data Processing. Based on our evaluation criteria, we need to sort out the data and constrain it to the range of $[0,100]$. This requires us to first normalize the indicators. The types of indicators have been given in the figure. For example, the food supply diversity indicator is a positive indicator, the consumption of resources is a negative indicator, and the equity index is a neutral indicator. We have adopted different processing methods for different indicators:

For positive indicators:

$$x = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \times 100$$  \hspace{1cm} (7)

For negative indicators:

$$x = \frac{x_{\max} - x}{x_{\max} - x_{\min}} \times 100$$  \hspace{1cm} (8)

For neutral indicators:

$$x_i = 1 - \frac{|x_i - x_{best}|}{M}, \quad \text{where} \quad M = \max(|x_i - x_{best}|)$$  \hspace{1cm} (9)

We convert each indicator into a percentage system by multiplying by 100. The $x_{best}$ is the expected value, as for the neutral indicators in this article, the best value is 1/2 to represent the best value of gender equity.

3.2. Evaluation of Attributes

3.2.1. Measure of profitability and efficiency. The PEFS model built can already calculate the value of efficiency and profit, in a range of (0, 1). In order to establish a unified scoring standard, we define the evaluation of efficiency and profitability as the following form:
Where \( \eta, \omega \) is the output of PEFS model?

3.2.2. Measure of Sustainability & Equity. The sustainability of the food system was estimated based on three secondary indicators: REC (resources and energy consumption), EP (environmental pollution) and FSA (food safety). Two secondary indicators of GE (Gender Equity) and II (Infrastructure Equity) those are used to measure the equity of the food system.

Each secondary indicator is divided into several tertiary indicators. It can be seen from 5.1.3 that the tertiary indicators have been normalized and the size is limited to \([0,100]\). The entropy method was used to calculate the weight of these three indicators, and the score of the secondary indicator was obtained. Then the entropy method combined with the TOPSIS method was used to calculate the sustainability and equity scores for the secondary indicators. The steps of the TOPSIS method combined with the entropy method are as follows:

Step1: Calculate the priori probability matrix
We use the ratio of the individual data to the sum of its columns as the priori probabilities of the data, according to which the probability matrix is:

\[
\begin{bmatrix}
\frac{p_{11}}{\sum_x}, & \frac{p_{12}}{\sum_x}, & \cdots, & \frac{p_{1q}}{\sum_x} \\
\frac{p_{21}}{\sum_x}, & \frac{p_{22}}{\sum_x}, & \cdots, & \frac{p_{2q}}{\sum_x} \\
\vdots & \vdots & \ddots & \vdots \\
\frac{p_{n1}}{\sum_x}, & \frac{p_{n2}}{\sum_x}, & \cdots, & \frac{p_{nq}}{\sum_x}
\end{bmatrix}
\]  

In the equation:

\[ p_y = \frac{x_{ij}}{\sum x_{ij}} \]  

is standardized statistics.

Step2: Calculate information entropy
For each data, we redefined its information entropy as:

\[ e_y = -\frac{q}{\ln q} \frac{x}{\sum_y} p_y \ln(p_y) \]  

In the equation:

\( j \) Is the index number? \( j = 1, 2, 3, \ldots q \)

Step3: Define information utility values to calculate entropy weights
Considering the information utility value reflects the amount of information, we define the information utility value as follows:

\[ d_j = 1 - e_j \]  

The entropy weight is expressed as:

\[ W_j = \frac{d_j}{\sum_{j=1}^{q} d_j}, (j=1, 2, \ldots q) \]  

Step4: Calculate the best and worst distance
The maximum value:
\[ E^+ = \left( \max \{e_{11}, e_{21}, \ldots, e_{n1}\}, \max \{e_{12}, e_{22}, \ldots, e_{n2}\} \ldots \max \{e_{1q}, e_{2q}, \ldots, e_{nq}\} \right) \]  
\( (15) \)

The minimum value:

\[ E^- = \left( \min \{e_{11}, e_{21}, \ldots, e_{n1}\}, \min \{e_{12}, e_{22}, \ldots, e_{n2}\} \ldots \min \{e_{1q}, e_{2q}, \ldots, e_{nq}\} \right) \]  
\( (16) \)

The worst distance:

\[ D_i^+ = \sqrt{\sum_{j=1}^{q} (E_j^+ - e_{ij})^2} \]  
\( (17) \)

The best distance:

\[ D_i^- = \sqrt{\sum_{j=1}^{q} (E_j^- - e_{ij})^2} \]  
\( (18) \)

In the equation, \( j \) is the number of indicators in the data set.

Based on the above formula, the score was calculated as: \( S_i = \frac{D_i^-}{D_i^+ + D_i^-} \), the sustainability and equity can be obtained this way.

3.3. Results

Bringing the data into the stability evaluation model for calculation, we get the results of the stability of the food systems of various countries around the world, that is, the evaluation of the level of efficiency, profitability, sustainability, and fairness. Display the results on the map, as shown in the figure below:

![Figure 6. Level of stability of food systems in each country.](image)

We use the color scale to indicate the value, where the redder the color, the lower the corresponding indicator relative to the global level. The greener the color, the higher the corresponding index relative to the global level. Analyzing the stability levels of different food systems, we have the following findings, which are applicable to most situations:
The efficiency and profitability of the food system are similar in the same region, such as Argentina, Russia, and Australia. The color is close to orange, indicating that the efficiency and profitability of the food system in these countries are relatively low.

The color distribution on the efficiency and profitability map is very uneven, indicating that the imbalance of overall efficiency and profitability of the food system. Similar results of Equity map illustrates the unreasonable distribution of food in the world and the large gap between rich and poor.

Based on the above findings, the correlation coefficients of these four indicators were calculated to further verify the correlation relationships:

![Correlation coefficients of the 4 above indicators.](image)

In the figure, the colors varying from light to dark indicate that the correlation coefficient values from low to high (including negative numbers). From the first to the fourth column (row), the indicators are Equity, Sustainability, Profitability and Efficiency.

The region of efficiency and sustainability have the lightest color where the lowest correlation coefficient is -0.77, indicating that efficiency and sustainability have a significant negative correlation.

The distribution of the food system is not balanced. Judging from the indicators we have selected, the imbalance of the current food system reflected the inequitable distribution of male and female, and the unreasonable regionally distribution of basic food on a global scale.

Although the deaths of famine are few in the world, quantities of people in malnutrition around the world and distributed in a wide range of areas.

Therefore, we must optimize the existing food system to make it pay more attention to the equitable distribution and sustainability.

### Strength

The establishment of stability evaluation indicators food system Model comprehensively considers the factors that affect the stability of the food system, and the calculation results of the stability evaluation indicators can well measure the stability of different food systems.
The establishment of the food system model considers the factors of efficiency, profitability, sustainability and fairness. The model expresses the mathematical model of the food system through the connections between different factors, and reveals the inner connections of the food system accordingly.

3.5. Weakness
The solution of optimized model is a little more complicated, which took long time.

4. Conclusion and Suggestions
When a food system is optimized for sustainability and fairness, the following conclusions are drawn:

The SI increase along with the efficiency and profitability of most food systems will decrease, which is obviously very different from our current food system that focuses on profitability and efficiency.

The benefits and costs of such optimization are different in developed and developing countries. After optimization, various indicators in developed countries have changed more. Here we believe that developed countries have sufficient resources and technological strength, etc. If the country is willing to change the focus of the food system, the effect is more obvious. Developing countries is opposite.

At the aim of making one’s own food system more stable, the production structure, scientific and technological investment, market concepts and ecological protection awareness should be considered by each country when making different levels of efforts according to their respective national conditions.

References
[1] High Level Panel of experts on food security and nutrition of the committee on world food security (HLPE). Nutrition and food systems [internet]. HLPE; 2017.
[2] Max Roser and Hannah Ritchie (2013) - "Hunger and Undernourishment". Published online at OurWorldInData.org. Retrieved from:
[3] 'https://ourworldindata.org/hunger-and-undernourishment' [Online Resource]
[4] Hannah Ritchie (2020) - "Environmental impacts of food production". Published online at OurWorldInData.org. Retrieved from:
[5] 'https://ourworldindata.org/environmental-impacts-of-food' [Online Resource]
[6] : Poore, J., & Nemecek, T. (2018). Reducing food’s environmental impacts through producers and consumers. Science, 360(6392), 987-992.
[7] : Aiello Giuseppe, Enea Mario, Muriana Cinzia, Economic benefits from food recovery at the retail stage: An application to Italian food chains, Waste Management,
[8] Volume 34, Issue 7,2014, Pages 1306-1316,ISSN 0956-053X,