Costs and Benefits of Food System Optimization

A Case Study of Germany and Jordan

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Abstract. The current global food system still prioritizes efficiency and profitability, which is unstable. Especially confronted with the impact of COVID-19, the uncertainty further increases. Therefore, with an attempt to establish a food system optimization model prioritizing equity and sustainability, we proceed as follows. Firstly, we use the integrated entropy weight method (EWM) and the analytic hierarchy process (AHP) to establish the SEPE model to evaluate the priority of four aspects: efficiency, profitability, sustainability and equity. Then, in order to achieve the goal of maximizing the score of equity and sustainability, we establish GOV model based on linear regression to simulate the optimization measures in food system. Then, We take Germany and Jordan as examples for model application. For Germany, the optimization time is 12 years, the proportion of optimization cost in GDP is 6.5% (279.5 billion dollars), and the malnutrition rate is 0.00034% close to 0. For Jordan, the optimization time is 8 years, the optimization cost accounts for 120% of GDP (85.75 billion dollars), and the malnutrition rate drops to 3.3% remaining at a low level. The results show that developing countries are at a low disadvantage, which calls for international cooperation and humanitarian assistance.

Keywords: Food System · Indicator System · Linearization Regression

1 Introduction

The term food system refers to the constellation of activities involved in producing, processing, transporting and consuming etc. [3]. The health of our food systems profoundly affects the health of our bodies, as well as the health of environment on the earth. When they function well, food systems have the power to bring us together as families, communities and nations. However, our current global food systems model prioritizes efficiency and profitability, which is vulnerable even in the parts of the world that generally serves well. Millions of people around the globe have experienced first-hand during the COVID-19 crisis. United Nations has warned that 25 countries are at

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serious risk of famine this year and the planet could experience its worst food crisis in 50 years [4]. Hence, re-optimizing a comprehensive food system model to access equity and sustainability appears a reasonable and warranted endeavor, and then we draw up a plan to alleviate the food crisis.

The main studies to evaluate the current food system include: World Food Insecurity Report 2013 released by FAO in 2013: *The State of Food Insecurity in the World 2013: The Multiple Dimensions of Food Security* including Food Availability, Food Stability and Food access Food Utilization. The food system evaluation index system was established and the food system status of 157 countries and regions in the world was evaluated [2]. The Economist Intelligence Unit released *Global Food Security Index 2014: An Annual Measure of the State of Global Food Security*, 19 indicators are selected from three dimensions: food affordability, food availability, and food quality and safety. The food safety evaluation index system was established and the food safety status of 109 countries and regions was evaluated [5]. These studies all show that the current food system is unsafe and unbalanced, so a more equitable and sustainable food system is necessary. However, the current evaluation model is not comprehensive, focusing on the food system security, ignoring the sustainable development of the food system, and further related studies lack of cost and benefit analysis of the food system optimization, which hinders the process of the food system optimization. So we did the following.

First, we established a comprehensive evaluation model based on multiple indicators for the food system, referred to as the SEPE evaluation model. Secondly, in order to improve the priority of equity and sustainability in the food system, we established a GOV optimization model based on linear regression fitting. After that, We used Germany and Jordan as representatives of developed and developing countries, and defined the tipping point when the food system equity and sustainability score exceeds the profitability and efficiency score for the first time. We use it to calculate the system optimization time. Furthermore, we use linear programming and gray prediction to analyze the cost, and take the change of malnutrition rate as an example to reflect the benefits of the optimization of food system.

2 Materials and Methods

2.1 Data Collection and Preprocessing

We collect data from databases like Food and Agriculture Organization of the United Nations, Oxford University's website Our World in Data, The World Bank etc. and the selected normative indicators have good data coverage in the world. For minority of missing data, we use the expectation maximization method in SPSS to fill in. Firstly, the missing values are filled with the expected values, and then the maximum likelihood estimation is used to iterate until convergence, so as to improve the accuracy of the data.

2.2 Establishment of the SEPE Evaluation Model

We set up the SEPE evaluation model to evaluate the ability of a country's food system in terms of efficiency, profitability, sustainability and equity. We call them the first level indicators. Then we set 15 secondary indicators as a factor affecting the first level indicators (Table 1). For secondary indicators, we define the indicators that only affect one primary indicator as one-way indicators, while the indicators that affect multiple primary indicators are multi-directional indicators. According to the different aspects of the impact, it can be divided into positive indicators (+) and negative indicators (−). Some secondary indicators have both positive and negative effects. Based on different levels of food security, we selected 40 countries for analysis by stratified sampling method.

From Table 1 we assume the following four formulas:

$$\mathrm{EI} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 \tag{1}$$

$$\mathrm{PI} = \xi_1 X_4 + \xi_2 X_5 + \xi_3 X_6 + \xi_1 X_7 \tag{2}$$

$$\mathrm{EQI} = \theta_1 X_8 + \theta_2 X_9 + \theta_3 X_{10} + \theta_4 \tag{3}$$

$$\mathrm{SI} = \lambda_1 X_{12} + \lambda_2 X_{13} + \lambda_3 X_{13} + \lambda_4 X_{14} \tag{4}$$

(EI: Efficiency index PI: Profitability index
EQI: Equity index SI: Sustainability index)

2.3 Determination of Weight

For the weights of the secondary indicators corresponding to the primary indicators, we use the Entropy Weight method and the Analytic Hierarchy Process to determine. First, we use entropy weight method to get the weight according to the existing data, then refer to the weight to construct the comparison matrix for AHP, and get the final weight after consistency test. The specific steps are as follows:

First, the existing data are dimensionless by the following formula.

$$y_{ij} = \begin{cases} \frac{x_{ij} - \min(x_i)}{\max(x_i) - \min(x_i)}, & positive\ indicator \\ \\ \frac{\max(x_i) - x_{ij}}{\max(x_i) - \min(x_i)}, & negative\ indicator \end{cases} \tag{5}$$

In this way, we get the dimensionless data of the i th secondary indicator of the j th country, and then normalize the data of all countries:

$$q_i = \frac{y_{ij}}{\sum_{j=1}^{n} y_{ij}} \tag{6}$$

According to the concepts of self-information and entropy in information theory, we can calculate the information entropy of each evaluation index:

$$e_i = -\ln(n)^{-1} \sum_{j=1}^{n} q_{ij} \ln\left(q_{ij}\right) \tag{7}$$

Table 1. The food system evaluation criteria

First-level indicator	Second-level indicator	Unit	Explanation
Efficiency	Roads Density (X_1)	mile per area	The denser the roads, the easier to transport food around the country
	Food Per Capita CO2 Emissions (X_2)	ton per capita	The bigger carbon dioxide emissions(food), the faster process cycle
	Per capita fossil fuel consumption (X_3)	ton per capita	The more fossil fuels burned per capita, the faster transportation
Profitability	per capita food waste (X_4)	ton per capita	Food waste leads to excessive demand for food in the market
	Per capita grain production (X_5)	ton per capita	The larger the per capita grain production, the greater demand profit space
	Food Price fluctuation Index (X_6)	%	The larger fluctuation, the more drastic the food markets change
	Per capita food expenditure (X_7)	dollar per capital	The more food expenditure, the stronger the consumption capacity
Equity	per capita food waste (X_8)	ton per capita	the more serious food waste, the lower degree of equity in food distribution.
	Food Price fluctuation Index (X_9)	ton per capita	The more frequent fluctuations, the more unfair impact on consumers.
	Malnutrition ratio (X_{10})	%	It refers to the lack of food supplies and people at the bottom stay in hunger.
	Main food insecure morbidity (X_{11})	%	The lower coverage of high-quality food, the lower equity people get
Sustainability	per capita food waste (X_{12})	ton per capita	It causes increase of greenhouse gas emissions and the environment worse.

(*continued*)

Table 1. (*continued*)

First-level indicator	Second-level indicator	Unit	Explanation
	Per capita grain production (X_{13})	ton per capita	The larger grain production, the more sufficient the grain reserve.
	Food Per Capita CO2 Emissions (X_{14})	%	Excessive emission of carbon dioxide will cause environmental problems.
	Per capita fossil fuel consumption (X_{15})	ton per capita	Fossil fuel consumption causes series of environmental problems.

Based on information entropy, we will further calculate the weight of each evaluation index defined above:

$$w_i = \frac{1 - e_i}{k - \sum_{i=1}^{k} e_i} \tag{8}$$

We put the weight result of entropy weight method into the pairwise comparison matrix of AHP criterion layer. When all the matrices pass the consistency test, we get the final weight.

2.4 GOV Re-optimizing Model

From the SEPE model, we conclude that the efficiency and profitability of the food system in most countries of the world are given priority. In order to improve the sustainability and fairness of the food system, we propose the GOV optimization model:

$$y_i = \hat{a}e^{n-d} \ln\left(e + \left(\frac{1}{e} - 1\right)\alpha\right) + y_{i-1} \tag{9}$$

among this,

$$n = \frac{y_{i-2} - y_{i-1}}{\hat{a}} \tag{10}$$

The application method of the model is as follows: firstly, select the multi-directional indicators which needs to be optimized in the food system, and according to the corresponding data and the regression coefficient $\hat{a}$ was obtained by linear regression, Then calculate whether the value of n is less than the government capacity threshold m (usually < 1). If it is less than, the optimization will be completed. If it is greater than, the optimization can continue. Parameter α (The value of [0,1]) is the government's willingness to optimize, and the higher the value is, the more resolute the government's attitude is; The parameter d (with the value of $(1, \infty]$) represents the government's expectation of the optimization result. The closer the value is to 1, the higher the expected effect is. In this way, we can get the optimized data of the food system.

3 Results and Discussion

According to the GOV and SEPE evaluation models constructed above, we selected Jordan and Germany as the representatives of developing and developed countries to conduct cost-benefit analysis of food system optimization. The cost is the proportion of intervention time and fiscal cost to national GDP, in which national GDP is analyzed by using the grey forecasting model based on GM(1,1). Intervention time is the time it takes for the food system to change to priorities that are equity and sustainability. The benefits of food system optimization are represented by the reduction in malnutrition rates.

3.1 Germany

3.1.1 Optimization Results

We put German data into the SEPE model to obtain efficiency and profitability scores and sustainability and equity scores before and after optimization. From the comparison of the pictures, we can see that the German food system before optimization basically gave priority to efficiency and profitability. After optimization, the German food system scores lower in efficiency and profitability, and higher in sustainability and equity. Although the former score is still higher than the latter, the score is very close (Fig. 1).

3.1.2 Costs and Benefits Analysis

3.1.1.1 The Analysis of Cost

In the optimization process, we find that when the fairness and sustainability score is 0.47407 as the tipping point, starting from 2020, Germany will realize the optimization of the food system in 2032, spanning 12 years. We continue with the proportion of budget to GDP in the optimization process, P is the optimization cost. In order to ensure the scientific results of calculation, we first collected the GDP of Germany from 2010 to 2020. Due to the small number of forecasts, we use the grey forecasting model based on GM(1,1) to forecast the GDP of Germany in 2020–2034. We get that when the German food system is optimized for the first time, P is 0.0065, that is, the total cost of realizing the optimization of the food system accounts for 6.5% of the GDP of the year, which is 279.5 billion dollars (Fig. 2).

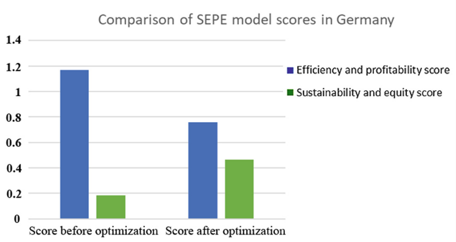

Fig. 1. Comparison of SEPE model scores in Germany

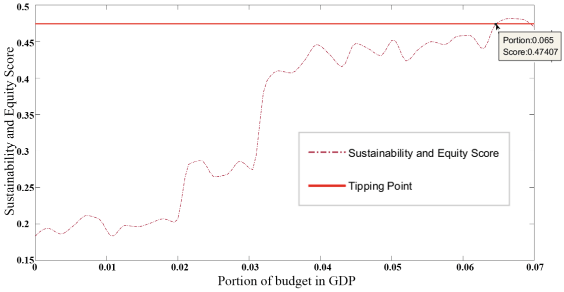

Fig. 2. Tipping point identification and intervention costs in Germany

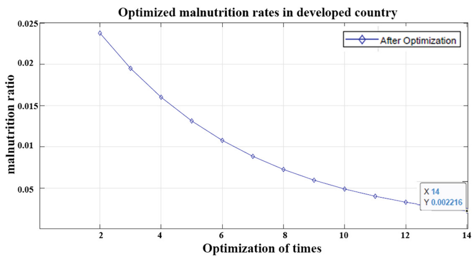

Fig. 3. Optimized malnutrition rates in Germany

3.1.1.2 The Analysis of Benefits

After fitting the data of developed countries, we use the GOV model to optimize, and the results are shown in the Fig. 3. As can be seen from the Fig. 4, the malnutrition rate of developed countries in the 14th year is 0.002216, which is close to zero, so the problem of malnutrition is basically solved.

3.2 Jordan

3.2.1 Optimization Results

We brought Jordan's data into the SEPE model to derive efficiency and profitability scores and sustainability and equity scores before and after optimization. As can be seen from the comparison of the pictures, Jordan's food system before optimization also gave priority to efficiency and profitability, but its score was much lower than that of Germany.

3.2.2 Costs and Benefits Analysis

3.2.1.1 The Analysis of Cost

In the optimization process, we found that when the fairness and sustainability score is 0.33567 as the tipping point, starting from 2020, Jordan will achieve the optimization of the food system in 2028, a span of 8 years. Similar to the analysis of Germany, we combined the grey prediction to predict the GDP of Jordan in 2020–2030 by using the GDP of Jordan during 2010–2020. We obtained that when the food system of Jordan was

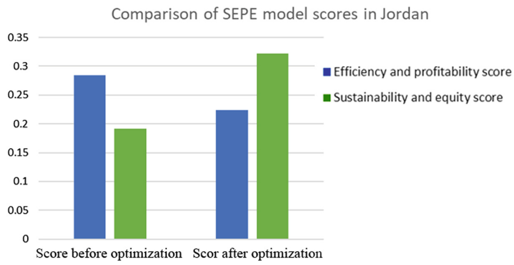

Fig. 4. Comparison of SEPE model scores in Jordan

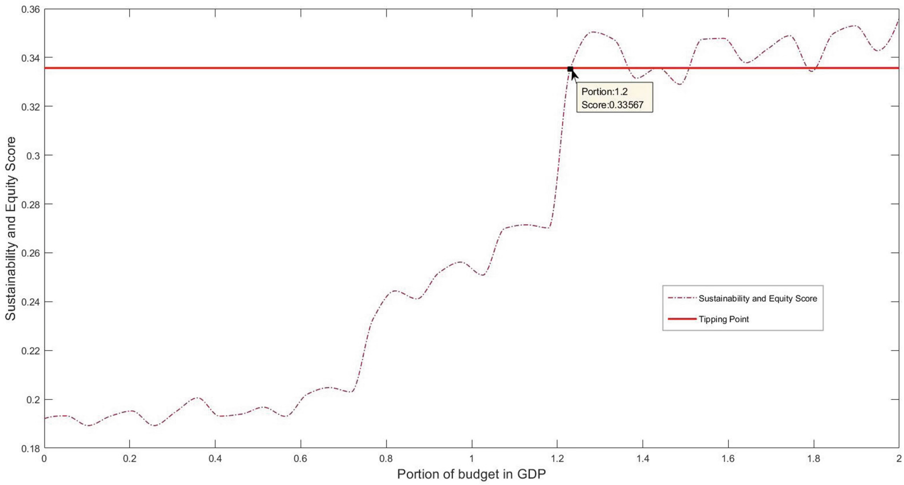

Fig. 5. Tipping point identification and intervention costs in Jordan

optimized for the first time, P was 1.2, that is, the total cost of realizing the optimization of the food system accounted for 120% of the GDP of that year, which was 85.75 billion dollars.

3.2.1.2 The Analysis of Benefits

After fitting the data of Jordan, we use the gov model to optimize, and the results are shown in the Fig. 5. In the Fig. 6, we can see that although the malnutrition rate has dropped to a low level of 2.4%, there is still a gap between ending hunger. Therefore, we can draw a conclusion that the food system of developing countries can be optimized to a great extent to reflect sustainability and equity. However, this does not mean that developing countries have eliminated malnutrition.

3.3 Reasons for Choosing Germany and Jordan

We chose Germany and Jordan as the representatives of developing and developed countries to further verify the accuracy of the previous conclusion. For Germany, in the SEPE

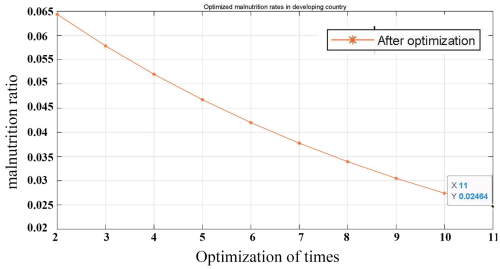

Fig. 6. Optimized malnutrition rates in Jordan

model, it is at the forefront in terms of per capita food CO2 emissions, per capita fossil fuel consumption and road density. Therefore, we believe that Germany has great potential in the optimization of food system and is more representative. For Jordan, according to statistics, 15% of Jordanian households are facing food crisis in 2020 due to logistics disruption, rising import prices due to rising costs of trade finance, temporary restrictions on movement and closure of some markets, especially the emergence of a new outbreak [1]. Therefore, the food system optimization model for Jordan has practical significance.

4 Conclusion

Based on these results, we can see that the current food system still prioritizes efficiency and profitability, which requires government interventions to translate priorities into sustainability and equity in order to better meet the current challenges. At the same time, compared with the developed countries represented by Germany and the developing countries represented by Jordan, we can see that the intervention costs of the developing countries are higher and the benefits of the intervention is poor, which puts forward the requirements for international cooperation and humanitarian assistance. From the perspective of quantitative analysis, this study makes up for the blank of cost and benefit analysis of food system optimization, and the direction of food system optimization in the future should be universality and sustainability.

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