Study on the Sustainability of Food System

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Abstract

In this paper, we establish a model to create a sustainability score to evaluate the sustainability of a food system. Sustain score is based on 8 sub indicators and a large amount of data processing and function fitting. We use these data to predict the continuous score after the optimization scheme. Then, through the model test, we get a significant increase in persistence - scores in different countries. In addition, we have established two models of exporting and importing countries in order to rearrange the proportion of crops. For each model, we tested developed and developing countries respectively. Because each country's situation is different, the cost of changing the model is also different. One country has an impact on its distribution efficiency, while the other country will reduce its profits in order to achieve the ideal distribution model. Finally, after the optimization scheme is completed, analytic hierarchy process (APH) is used to evaluate the food system again.

Keywords

Sustain Score; Sustainability; Food System; Analytic Hierarchy Process (APH).

1. Introduction

As for human, food is a source of energy, fuel, nutrition, which can bring people happiness and even influenced the social behavior. Our food comes from a variety of sources, and our daily diet can be roughly divided into: animal products, fish and other sea-foods, milk and cheese, fresh fruits and vegetables, ropcs and legumes, nuts and seeds, processed food. Agriculture is the most fundamental link in the functioning of the food system, providing sources of vegetable oils and refined sugar, and is an important source of feed for animal products. Therefore, how to optimize the agricultural system is actually affects the attributes of the world food system to a large extent. However, the global food system based on agriculture now faces two important challenges: the environmental problem and hunger. This is a vital flaw in our current food system.

Through the analytic hierarchy process (APH), we know that the current world food system is oriented by high efficiency and high profit, but this model inevitably leads to the disadvantages of environmental problems and hunger problems. The mechanization of agriculture, deforestation and increased use of chemicals have added to the world's environmental pressures. Food production accounts for more than a quarter of global greenhouse gas emissions. World hunger is the hunger accumulated on the global scale. There are two main factors – food insecurity and malnutrition. Food insecurity refers to limited or unreliable access to safe and nutritionally adequate food, while malnutrition is caused by diseases resulting from inadequate intake of biologically essential nutrients. According to a recent report by the world health organization, malnutrition affects one in three people worldwide, affecting all age groups and the world population, and causes half of the 10.4 million child deaths in developing countries each year. In our view, these shortcomings affect more the sustainability and fairness of the whole food system.

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2. Analyzation of Today's Food System

After thousands of years of the human's civilization development, the food system today seems well-developed and contributes to the world economy, however, there are almost 700 million people are suffered from hunger while grains are being sold at low prices in some countries[1][3].

Analytic hierarchy process (AHP) is the method we used to find out the main criterion that affect each procedure in the food system. The advantage of using the analytic hierarchy process is that it can be relatively simple and comprehensive to calculate the influence ratio of each factor on an object according to the material, which shows the importance of each criterion which are presented in the Fig.1. Farmer are response for producing, workers are in the charge of the parts like processing and transportation, and traders, the brokers of the food, take the responsibility of the import and outport the crop [2].

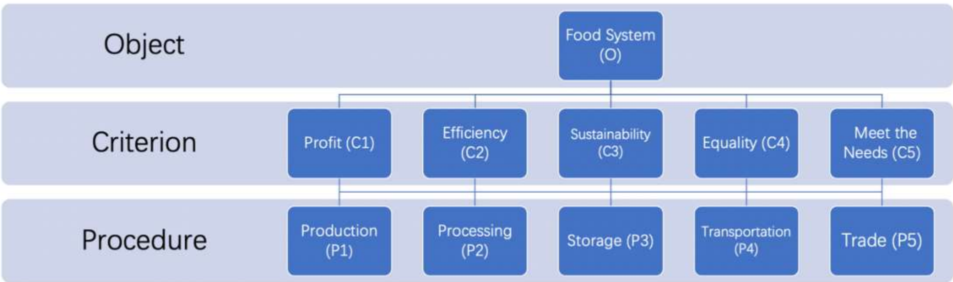

Fig. 1 The hierarchical chart of food system

Due to there are seven judgment matrix and each of them were evaluated and operated equally, we put the processing part as an example. It is necessary to noticed that the comparation in all matrixes are came from the relative materials and recording. The judgment matrix of the processing procedure is presented in table 1.

Table 1. The judgment matrix of the processing procedure

Processing	Profit	Efficient	Sustainability	Equality	Meet the Need
Profit	1.00	0.50	3.00	5.00	2.00
Efficient	2.00	1.00	4.00	5.00	4.00
Sustainability	0.33	0.25	1.00	1.00	0.25
Equality	0.20	0.20	1.00	1.00	0.25
Meet the Needs	0.50	0.25	4.00	4.00	1.00

The reason is that PJ fellows argues that processing part of the food supply chain needs to ensure many aspects of indexes such as water and nutrition retention. There are various processing methods such as hot processing or cold processing can be chosen. As a result, they choose to save resources and gain profits at the level of ensuring food nutrition and safety[4].

We use the arithmetic average method, the arithmetic square root method and the eigenvalue method in the analytic hierarchy process to calculate the weighted proportion of each factor to each process. The normalization method was also been used to make the statistics more valuable and usable. Table 2 shows the results of the proportions of each classification after calculation and integration.

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Table 2. Results of the proportions of each classification

	Weight of index	Profit	Efficient	Sustainability	Equality	Meet the Needs
Production	0.34	0.28	0.25	0.10	0.10	0.27
Processing	0.09	0.26	0.42	0.07	0.06	0.19
Storage	0.08	0.38	0.28	0.06	0.06	0.22
Transportation	0.17	0.24	0.47	0.12	0.06	0.12
Trade	0.32	0.47	0.23	0.07	0.07	0.16

In order to ensure the validity of the conclusion drawn by this method, the consistency test on each judgment matrix were carry out to ensure its logical rationality. There are five factors and five aspects in the model which make up six 5 by 5 matrices, therefore, n=5, we can find the eigenvalue of maximum λ_{max} by:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{[Aw]_i}{nw_i} \tag{1}$$

Then, calculate the value of coincidence indicator by:

$$\mathrm{CI} = \frac{\lambda_{max}-n}{n-1} \tag{2}$$

When n=5, RI = 1.12. Finally, the value of consistency ratio is:

$$\mathrm{CR} = \frac{CI}{RI} \tag{3}$$

The consistency ratio (CR) of all the matrix is less than 0.1 which means that the logic of our method passes the consistency check.

Through the final weighted calculation, we obtained the proportion of each bid evaluation, which are shown in table 3 and Fig.2.

Table 3. The proportion of each bid evaluation

Profit	Efficient	Sustainability	Equality	Meet the Needs
0.33	0.30	0.09	0.08	0.20

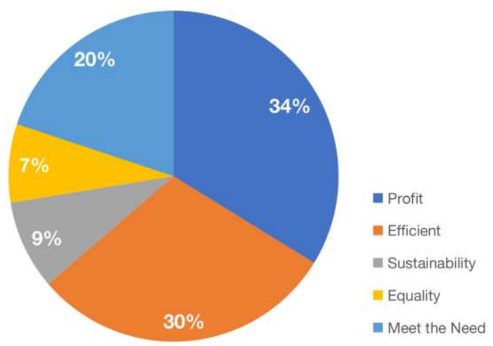

Fig. 2 The proportion of each bid evaluation

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From the Fig.2, it can be found that profit and efficient parts occupy the largest proportion, which are 0.33 and 0.3 respectively. Their sum is even more than half, by 0.63.

3. The Food Distribution Model

The structure of exporting country model is shown in Fig.3.

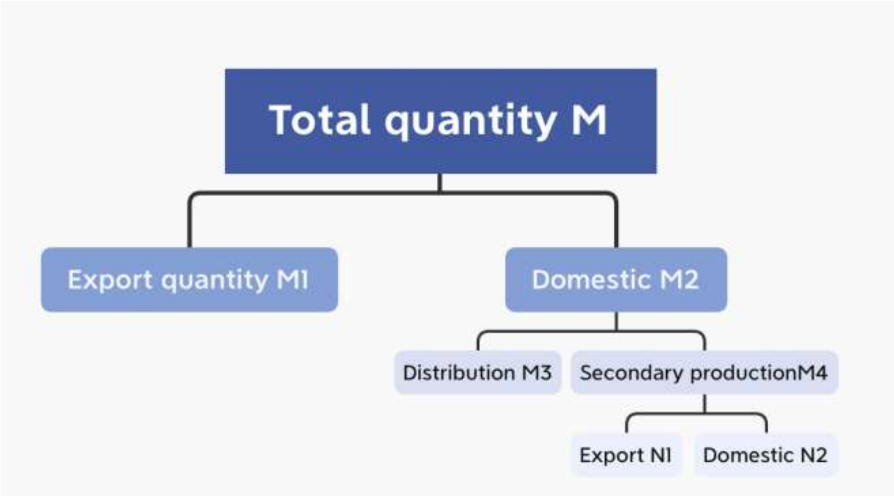

Fig. 3 The structure of exporting country model

However, considering the factors such as loss during transportation and food spoilage during. Storage, we correct the model as follows:

$$\begin{cases} M > M_1 + M_2 \\ M_2 > M_3 + M_4 \\ \gamma M_4 > (N_1 + N_2) \end{cases} \tag{4}$$

In 2007 and 2008 the price of the food increased sharply which can be fatal to the people who live in poverty [5]. So we correct our model by minus the food storage part:

$$\begin{cases} M > M_1 + M_2 \\ M_2 > M_3 + M_4 + 0.18M \\ \gamma M_4 > (N_1 + N_2) \end{cases} \tag{5}$$

After set up the ideal model and plug in the precise data, we can get an optimal value of $u = \frac{M_4}{M_2}$ this the proportion of the crop being used for further production. This will can also decide how long we will take to implement this system. Suppose the u_0 is the current rate and it will decrease α per year to reach the ideal system then we can gain the formula:

$$u = (1-\alpha)^n u_0 \tag{6}$$

where n is the time it will take to implement this system.

By using the Grey model, we can predict that in the next few years there will still be 2.8% people suffering from malnutrition, which means the domestic crop (M_3) can only support 97.2% people.

Let's take soybean as an example using this kind of crop to represent the whole distribution condition, which is shown in table 4.

Table 4. Data of soybeans and soybean derivative in Argentina (2018)

	Import(tones)	export(tones)	Production Quantity(domestic)	Domestic surplus
Soybean	4,547,682	10,053,802	55,263,891	49,757,771
Oil, soybean	3	5,043,233	7,249,000	2,205,767

The current value of M_3= and u are:

$$M_3 = 55{,}263{,}891 - 10{,}053{,}802 + 4{,}547{,}682 - 42{,}641{,}176 = 7{,}116{,}595\ ton \quad (7)$$

$$\text{u} = \frac{42{,}641{,}176}{49{,}757{,}771} = 0.857 \quad (8)$$

So far we can calculate the ideal M_3, M_4, u:

$$M_3 = 7{,}116{,}595/0.972 \approx 7{,}321{,}600 \quad (9)$$

$$M_2 - M_3 - 0.18M > M_4 \approx 32{,}488{,}671 \quad (10)$$

$$\text{u} = \frac{32{,}488{,}671}{49{,}757{,}771} = 0.653 \quad (11)$$

Then we can calculate the time may take to implement this system:

$$0.653 = (1-\alpha)^n 0.8577 \quad (12)$$

Let $\alpha = 0.05$ then it will took 5.3 years to achieve.

When the food of export country going aboard, the situation will be more complicated. Since it becomes a competition between nations. the richer country can buy as much as they want even exceed their need since it can offer more profit to the export country. The model aims to restrict the share of purchases depends on the population (q) of the import country and the domestic production. Let ρ be the average crop consumption, then we can have this formula:

$$P_1 + P_2 = pq \quad (13)$$

However, considering about the domestic food storage we have to correct the model to:

$$P_1 + 0.82P_2 = pq \quad (14)$$

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Also, since there will be loss during transportation, and the standard of reasonable loss in transportation is d so we correct our model to:

$$(1-\theta)P_1 + 0.82P_2 = pq \tag{15}$$

where P_1 is the ideal imports of the imports country. Then we can gain a value of ideal P_1 divide current is defined as ε.

$$\varepsilon = (1-\alpha)^n \tag{16}$$

The value of α can be positive for the rich country and negative for the country lack of food. n is the time the country will take to implement this system.

The impact of declining rate α on time is shown in Fig.4.

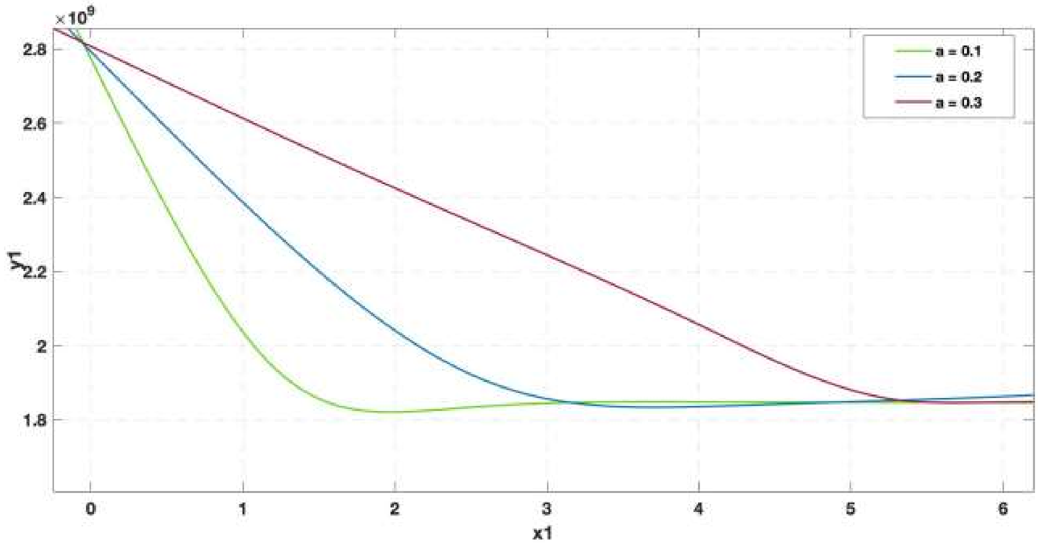

Fig. 4 The impact of declining rate α

when α= 0.2, n = 1.22, when α= 0.1, n = 2.58, when α= 0.05, n= 5.3. We can see from the chart that α= 0.05 is the best decline rate since the curve is declined gently which give country time to cushion the decline in profits.

4. The Food System Sustainability

We will optimize the sustainability of our food systems by alleviating stress on the environment and reducing the incidence of malnutrition. Therefore, the sustainability assessment indicators of food systems are divided into two dimensions: environment and nutrition.

In order to quantify the sustainability of a specific object, we created a permanent-score to represent the sustainability index of the whole system. The higher the score, the stronger the sustainability of the system.

The formula below presents the definition of the Sustain-score is shown in Fig.5.

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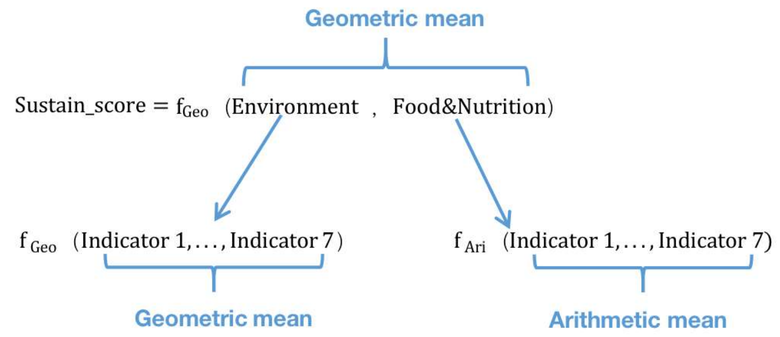

Fig. 5 Formula use to the Sustain-Score

As shown in Fig.5, sustain score is the overall rating, F is the calculation formula, and indicators respectively represent dimensional-related Indicators. According to the relevant rules of composite indicators and multi-criteria decision analysis, we obtained the following basic criteria.

In addition, if different elements/variables within a dimension are highly correlated with each other, arithmetic formulas should be used within that particular dimension. Conversely, if the degree of correlation between variables seems low, the geometric mean should be used, which is shown in Fig.6.

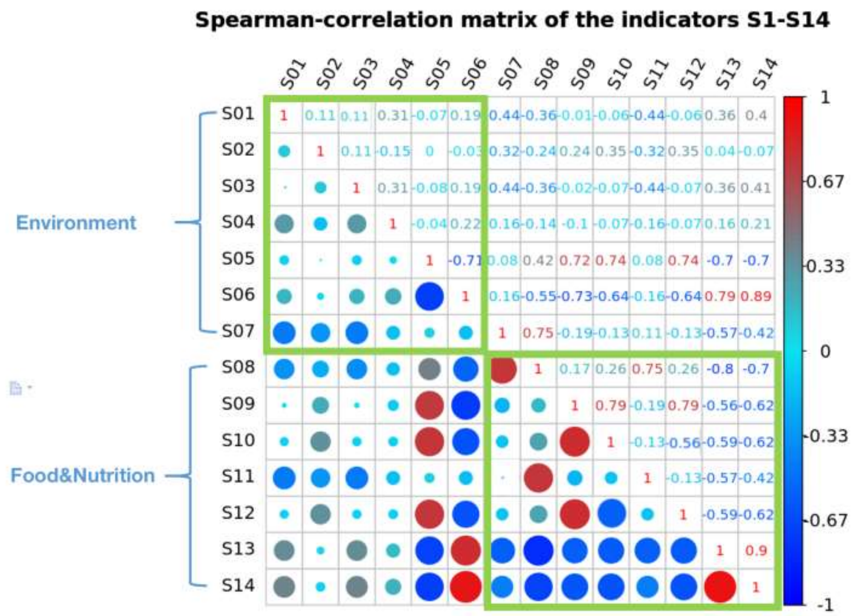

Fig. 6 Spearman-correlation matrix of the indicators S1-S14

As shown in the Fig.6, we used the correlation coefficient graph to show the internal crossover relationship before the index. The upward-triangle part is the correlation coefficient between indicators. Positive and negative represents each of the correlation respectively, while the absolute value represents the correlation. The downward triangle was a correlation visualization shown by circle pattern, with the red indicating positive correlation and the blue indicating negative correlation. The circular area indicating the magnitude of the correlation.

However, we can also find that in period 2019-2020, because of the Covid -19, all the food system has been heated, which is shown in Fig.7.

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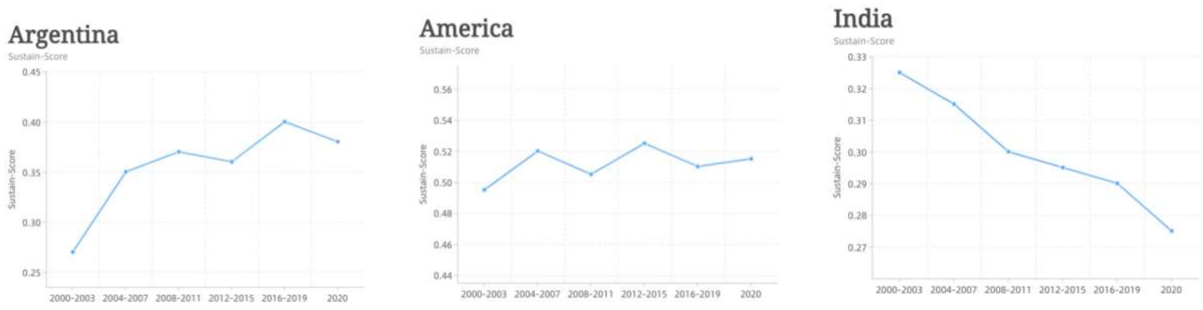

Fig. 7 Sustain-Score illustrated through the case of Argentina, America and Inndia

5. Optimization Solution

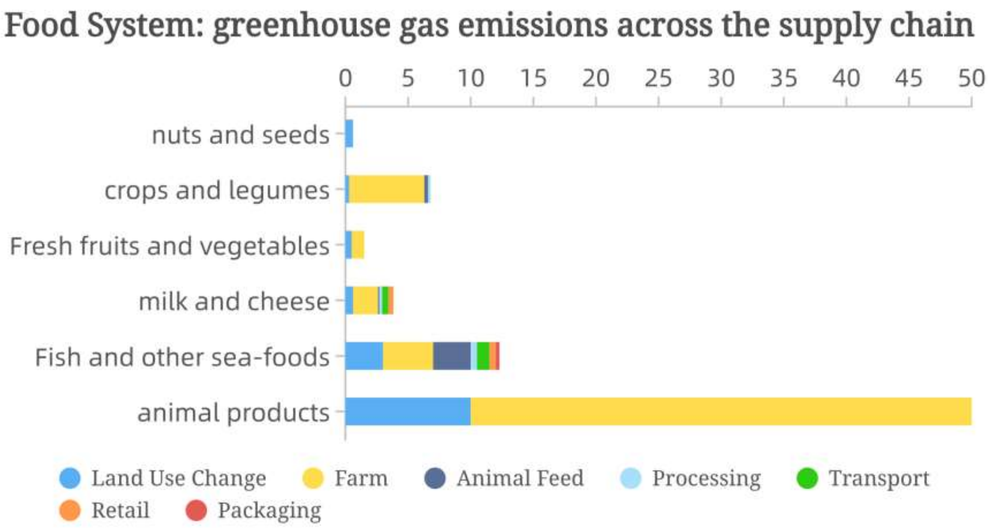

Fig. 8 Food system: greenhouse gas emissions across the supply chain

From Fig.8, we know that animal-based food causes the largest greenhouse gas emission in the world, and this harm mainly occurs in land use and farm.

When evaluating of the impact of different dietary patterns on Resources, ecological quality and human health through Tettamanti's, it is not difficult to see that the diet impacts less on human health and the most environmentally friendly diet is the vegetarian diets. Therefore, the world can adjust from omnivorous diets (based on products derived from conventional farming and nonorganic agriculture) to vegetarian diets (based on products derived from organic farming and agriculture). Due to vegetarian(or vegan) diets have less impact on health, they can play an important role in reducing hunger and malnutrition in poor countries.

As can be seen from the Fig.9, during the predicted period from 2020 to 2040, the food system sustainability of Argentina still reached a steady improvement and finally tends to be stable, while India's sustain-score is in a significant improvement. As a developed country, the score of the United States has improved but remains stable between the threshold. To conclude, before optimization, the country with lower maintain-score has the greater improvement of its environment and malnutrition after optimization.

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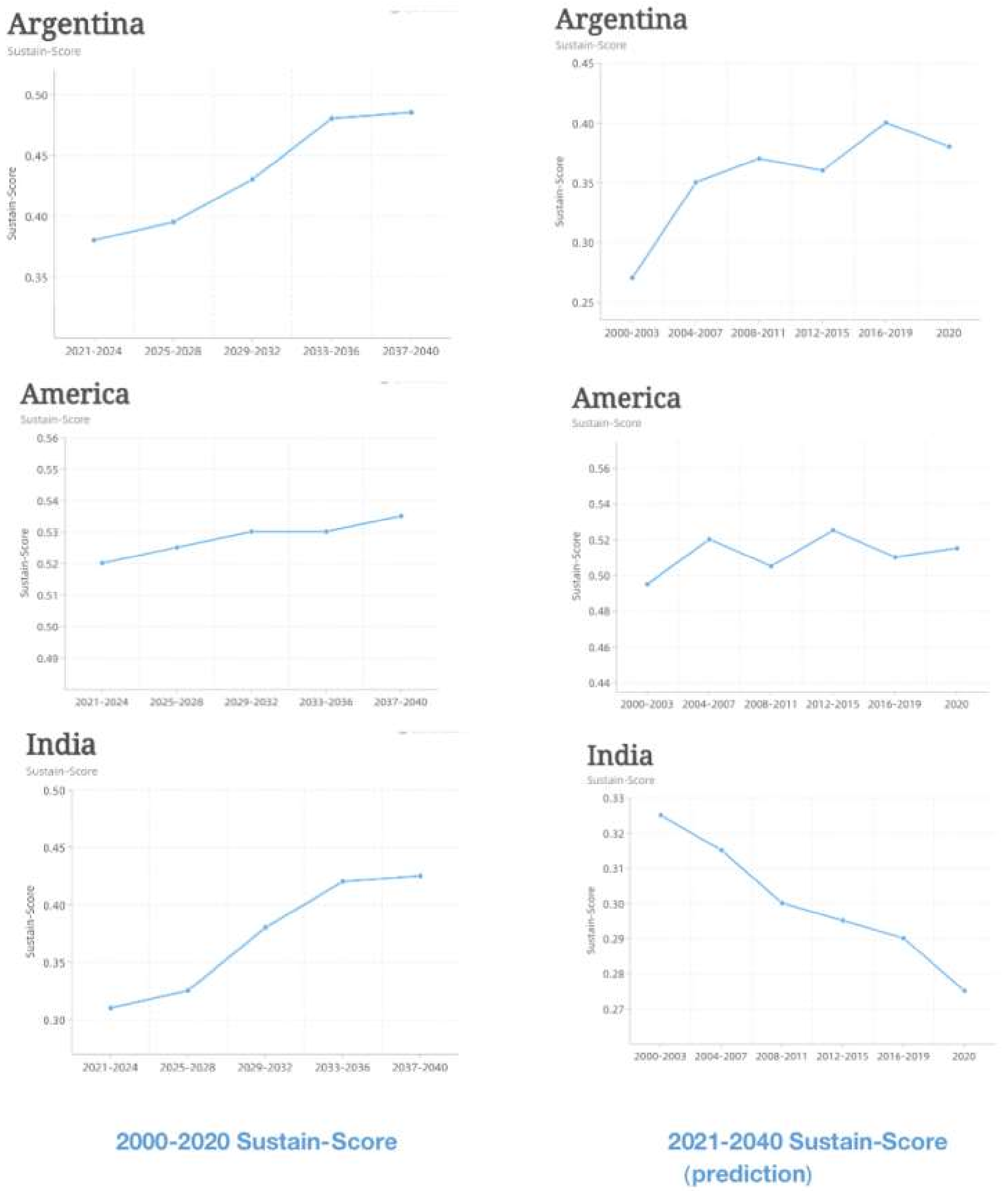

Fig. 9 Value of food systems

In terms of sustainability, we adjusted from the current omnivorous diet based on conventional agriculture to a plant-based diet based on organic agriculture. In terms of equality, we de-emphasized profit and prioritized whether the food supply was equally distributed to everyone. This has reduced the oversupply of food in some areas while the lack of food in others. AHP was used and the final conclusion was shown in table 5.

Table 5. The final conclusion

Profit	Efficient	Sustainability	Equality	Meet the Needs
0.16	0.19	0.21	0.25	0.20

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The result displays that the proportion become more equal now. Equality account for the lion part in he whole chart while profit take up the less one which make a great difference with Fig.10

The Fig.10 gives a clearer comparison between the two AHP result. The following biggest part is taken up by the sustainability which is 21%. The needs and efficient old the same proportion of 19% respectively. Equality and sustainability used to be the less on consideration in the food system, however, after applying the models we set, some of the problem of the food supply chain could be solved. However, there are still many immature places which need to prove.

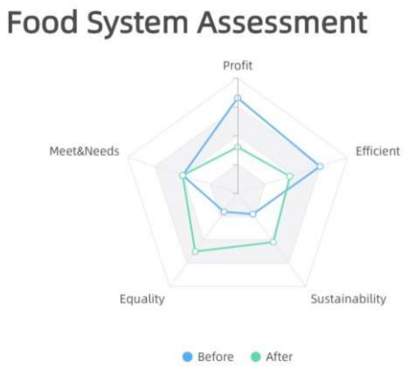

Fig.10 The two AHP results

6. Conclusion

In this paper, we study the sustainability of a food system. We use these data to predict the continuous score after the optimization scheme. Through the model test, we get a significant increase in persistence scores in different countries. In addition, we have established two models of exporting and importing countries to rearrange the proportion of crops. For each model, we tested developed and developing countries respectively. Finally, after the optimization scheme is completed, the food system is evaluated again by AHP.

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