Research on the Health and Sustainable Development of higher Education based on AHP and Grey Prediction

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Abstract. A healthy and sustainable higher education system has an impact on a country's efforts to further educate its citizens. In order to better evaluate and promote the healthy and sustainable development of higher education system, this paper establishes a model to evaluate the healthy and sustainable development of higher education. First of all, nine second-level indicators are selected and transformed into six first-level indicators by EWM, and a health assessment model is constructed by combining evaluation method with analytic hierarchy process. The improved AHP algorithm modified by CRITIC is used to calculate the weight of the first-level index, and the comprehensive score is the health index (HI) of the higher education system of various countries. Then taking the HI of each country's higher education system in 2018 as its current situation, it is found that China has great differences in various indicators, good funding conditions, and room for improvement. Finally, China is selected as the main analysis object to get the data of 28 sustainable development evaluation indicators in 7 aspects under the "7e framework", and the sustainable development evaluation model is constructed by using grey relational analysis (GRA). Then the influence degree of each index on system health is obtained.

1. Introduction

A healthy and sustainable system of higher education has the value as an industry itself and plays a significant role in promoting economic growth by providing trained and educated citizens. Both adjusting its national systems of higher education to reach a healthy state under pandemic and maintaining the effectiveness of higher education over an extended period of time have important influence to the nation's growth. Related policies need to be implemented in order to bring about institutional changes that can reach a more healthy and sustainable system [1].

Cost, access, equity, funding, value of a degree, quality of education, level of research and international communication are considered factors in order to assess the system's health and sustainability, and to analyze the policies required to migrate the nation to the proposed healthy and sustainable state[4-5].

2. Health assessment of higher education system

2.1. Features and Parameters of the Selection

Our indicator system consists of 6 first-level indicators reflecting whether the nation's system of higher education is healthy enough, which include access, equity, funding, quality of education, level of research and size. Consequently, 9 second-level indicators are constructed as an extension which include Gross enrolment ratio for higher education, the sex ratio of undergraduate students (SR), government funding to higher education institutions as a percentage of GDP, the number of top 500 universities in THE ranking by teaching, graduate pay level, graduate average employment rate, the number of top 500 universities in ARWU ranking, ratio of higher education institutions-1 million population, ratio of personnel-100 thousand population.

The closer that The sex ratio of undergraduate students is to 1 and the higher value of other indicators represents the better development status of HES in the nation.

2.2. Data source and preprocessing

Data selection is crucial to the model construction and result analysis. In order to fully guarantee the credibility, reliability and diversity of the data source, search the official department of education websites, statistical database and authoritative ranking website of several countries where the paper extract data of 10 countries with different economic development from 2010 to 2018.

Considering the difference of units and measurement objects among indicators, their difference is significant. Consequently, the paper normalize data for the following modeling. Since the closer that the value of SR is to 1 represents the better development status of HES in the nation, the paper use the formula below to convert it into positive data.

$$I_i^{'} = 1 - |1 - I_i| \tag{1}$$

The second-level indicators are processed by 0-1 Normalization.

$$I_i^{''} = \frac{I_i^{'} - \min(I_i)}{\max(I_i^{'}) - \min(I_i^{'})} \tag{2}$$

3. Health Assessment based on the combination of Entropy weight and Analytic hierarchy process

3.1. Integrating Metrics by Entropy Weight Method

As an objective weighting method, the Entropy Weight Method determines the weights of indicators according to the information provided by the data of each indicator.

In order to reduce the difficulty of calculation, the paper use the Entropy Weight Method (EWM) to obtain the weights of 2 second-level indicators which are Ratio of higher education institutions-1 million population (RHP) and Ratio of personnel-100 thousand population (RPP), and 3 second-level indicators which are Number of top 500 universities in THE rankings by teaching (NTT), graduate pay level (GP) and graduate average employment rate (GE). Then the paper respectively transform them into 2 first-level indicators: Size and Quality of Education (QE) by linear addition.

First, calculate the proportion p_{jk} of the kth second-level indicator of the jth first-level indicator.

$$p_{jk} = \frac{I_{j_k}^{''}}{\sum_{k=1}^{k} I_{j_k}^{''}} \tag{3}$$

Then the paper get the Entropy Value e_{jk} of the kth second-level indicator of the jth first-level indicator as below.

$$e_{jk} = -m' \sum_{k=1}^{k'} p_{jk} \ln(p_{jk}) \tag{4}$$

where $m' = \dfrac{1}{\ln(m)}$ and m is the number of the second-level indicators, i.e., the sample size. Calculate the information entropy redundancy.

$$d_{jk} = 1 - e_{jk} \tag{5}$$

where d_{jk} represents the information entropy redundancy of the kth second-level indicator of the jth first-level indicator. Then the paper calculate the weights of the indicators.

$$w_{jk} = \frac{d_{jk}}{\sum_{k=1}^{k} d_{jk}} \tag{6}$$

where w_{jk} represents the weight of the kth second-level indicator of the jth first-level indicator. Then obtain the first-level indicators by linear addition:

$$CI_j = \sum_{k=1}^{k'} w_{jk} I_{j_k}'' \tag{7}$$

Finally the paper get the weights of these indicators as the table below shows.

Tab. 1 The weight of second-level indicators by EWM

Size	
Ratio of higher education institutions-1 million population	0.6768
Ratio of personnel-100 thousand population	0.3232
Quality of education	
The number of top 500 universities in THE ranking by teaching	0.5411
Graduate pay level	0.3421
Graduate average employment rate	0.1168

3.2. Combination of CRITIC Method and AHP

CRITIC is a technique aiming at an objective resolution of multi-criteria decision problems. Objective weights derived from the method CRITIC are found to embody the information which is transmitted from all the criteria participating in the multi-criteria problem. The objective attributes of the data themselves are used for scientific evaluation. When the standard deviation is constant, the greater the conflict between indicators, the larger the weight is.

The paper obtain the weighting coefficients of each first-level indicator by CRITIC, an objective weighting method, and apply the result as the basis of measuring the importance of indicators two in AHP. Therefore, an objective comparison matrix is constructed. First of all, construct a data matrix where m is the number of samples and j is the number of indicators.

$$X = \begin{pmatrix} CI_{11} & \cdots & CI_{1j} \\ \vdots & \ddots & \vdots \\ CI_{n1} & \cdots & CI_{nj} \end{pmatrix} \tag{8}$$

Calculate the variability of indices.

$$\left\{ \begin{array}{l} \overline{CI}_j = \frac{1}{m} \sum_{n=1}^{m} CI_{nj} \\ S_j = \sqrt{\frac{\sum_{n=1}^{m} \left(CI_{nj} - \overline{CI}_j \right)^2}{m-1}} \end{array} \right. \tag{9}$$

where S_j represents the standard deviation. The indicator with larger standard deviation transmit larger amount of information and should be assigned higher weight.

Calculate the measure of the conflict created by indicators.

$$R_j = \sum_{j'=1}^{6} \left(1 - r_{j'j} \right) \tag{10}$$

where $r_{j'j}$ represents the correlation coefficient between the jth first-level indicator and each first-level indicator j'. Stronger correlation represent less measurement of conflict between the indicator and other indicators as well as more similar reflected information, which means the weight assigned should be reduced.

$$C_j = S_j \sum_{j'=1}^{6} \left(1 - r'_{jj}\right) = S_j \times R_j \tag{11}$$

C_i represents the amount of information. The higher the value C_j is, the larger the amount of information transmitted and the higher weight for j^{th} indicator.

Calculate the weights.

$$W_j = \frac{C_j}{\sum_{j=1}^{6} C_j} \tag{12}$$

The weights of 6 first-level indicators are calculated as the table below shows.

Tab. 2 Relative importance of first-level indicators

Indicator	Weight
Quality of education	0.1169
Level of research	0.1222
Size	0.1317
Equity	0.1623
Access	0.1882
Funding	0.2787

Then measure the importance of each indicators two two according to indicators' weights and obtain judging matrix as the figure below shows.
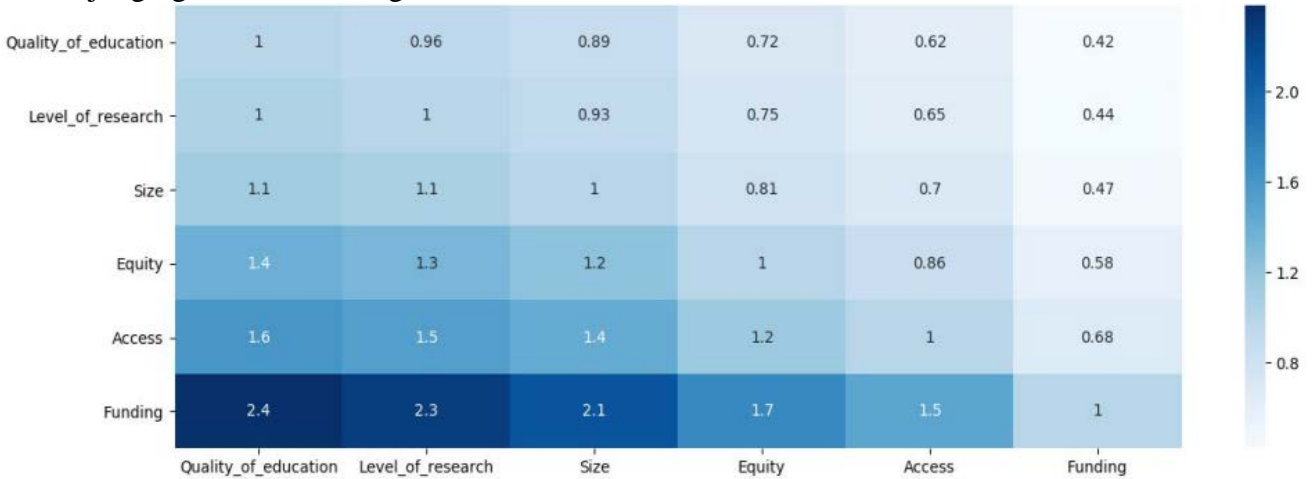

Fig. 1 The heat map of judging matrix

The following step is consistency check for the judging matrix.
Calculate the consistency index *CI*.

$$CI = \frac{\lambda_{\max} - 6}{5} \tag{13}$$

When the matrix is consistent matrix, if and only if its maximum eigenvalue $\lambda_{\max} > 6$ the paper calculate the consistency ratio CR.

$$CR = \frac{CI}{RI} \tag{14}$$

where RI stands for the index of average random consistency. By checking the chart the paper can obtain that the calculation results of CI and CR are 0.0360 and 0.0285 respectively, thus the matrix gets the satisfied consistency. The weight of each first-level index using eigenvalue method is shown in the following table.

Tab. 3 The weight of first-level indicators

Indicator	Weight
Quality of education	0.1136
Level of research	0.1179
Size	0.1280
Equity	0.1867
Access	0.1827
Funding	0.2711

Calculate the HI of each nation's system of higher education with the calculated weights and collected data of each nation in 2018.

$$H = \sum CI_j W_{(H)_j} \tag{15}$$

4. Grey prediction sustainable analysis model

The 7E framework to evaluate sustainable higher education is proposed by Yuqing Geng and others in [3] is a new and comprehensive one and enjoys the simplicity to remember and spread. It consists of 7 aspects and 28 indicators. The framework is integrated to evaluate sustainable higher education. The aspects and indicators well cover the connotations and goals of sustainability.

The following matrix is formed from the standardized data sequence of indicators of Chinese HES under the 7E Framework[1-3].

$$\left(A_1, A_2, \cdots, A_v\right) = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1v} \\ \vdots & \vdots & \vdots & \vdots \\ a_{u1} & a_{u2} & \cdots & a_{uv} \end{bmatrix} \tag{16}$$

Where v is the number of sample, $u = 1, 2, 3, 4$.

$$A_0 = \left(a_{10}, a_{20}, a_{30}, a_{40}\right)^T = \left(0.5151, 0.5202, 0.5223, 0.5163\right)^T \tag{17}$$

Use the following formula to calculate the correlation coefficient of the corresponding elements from each comparison sequence and the reference sequence.

$$\zeta_u(v) = \frac{\min_u \min_v | a_{u0} - a_{uv}| + \rho \cdot \max_u \max_v | a_{u0} - a_{uv}|}{| a_{u0} - a_{uv}| + \rho \cdot \max_i \max_k | a_{u0} - a_{uv}|} \tag{18}$$

where ρ is the resolution coefficient. $0 < \rho < 1$. The smaller the ρ is, the greater the difference between the correlation coefficients is. And the smaller the ρ is, the stronger the distinguishing ability is. Usually, the ρ is 0.5. For each comparison sequence, the paper calculate the average value of the correlation coefficient between each element and the corresponding element from the reference sequence, in order to reflect the correlation between each evaluation object and the reference sequence, i.e. the degree of correlation.

$$r_v = \frac{1}{28} \sum_{v=1}^{28} \zeta_u(v) \tag{19}$$

5. Analysis of the Result

5.1. The HI of each nation's HES

The HI of each nation's HES is exhibited in the below figure.

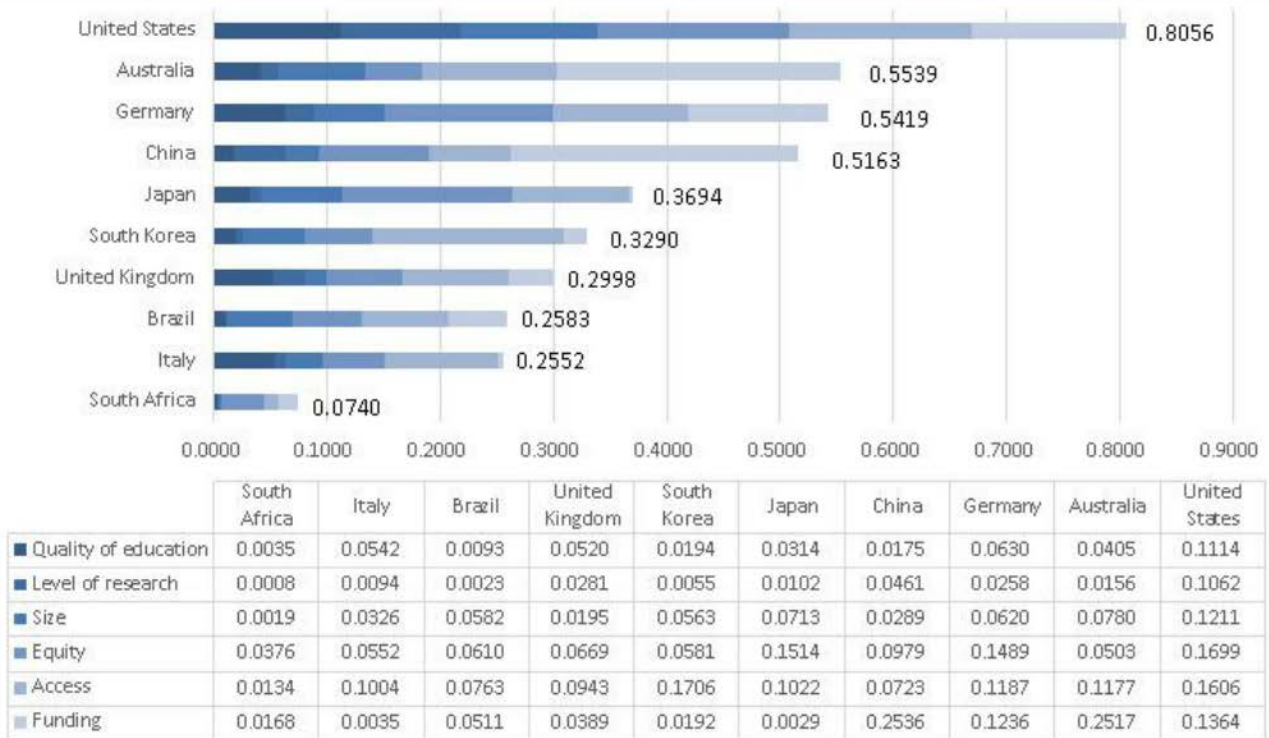|	South Africa	Italy	Brazil	United Kingdom	South Korea	Japan	China	Germany	Australia	United States
■ Quality of education	0.0035	0.0542	0.0093	0.0520	0.0194	0.0314	0.0175	0.0630	0.0405	0.1114
■ Level of research	0.0008	0.0094	0.0023	0.0281	0.0055	0.0102	0.0461	0.0258	0.0156	0.1062
■ Size	0.0019	0.0326	0.0582	0.0195	0.0563	0.0713	0.0289	0.0620	0.0780	0.1211
■ Equity	0.0376	0.0552	0.0610	0.0669	0.0581	0.1514	0.0979	0.1489	0.0503	0.1699
■ Access	0.0134	0.1004	0.0763	0.0943	0.1706	0.1022	0.0723	0.1187	0.1177	0.1606
■ Funding	0.0168	0.0035	0.0511	0.0389	0.0192	0.0029	0.2536	0.1236	0.2517	0.1364

Fig. 2 The HI of each nation's HES

It can be clearly concluded that the United States has relatively high composite scores for all indicators, and ultimately surpasses other countries with a HI of 0.8056,which means it has a well-functioning HES. Australia, Germany and China have HI scores above 0.5, and other countries have slightly lower scores. South Africa scores extremely low and its HES is considerably imperfect.

The figure above shows that the composite scores of various indicators in China vary greatly, and its Funding indicator with the largest weight ranks first. However, comparing with Japan and other countries with a health index greater than 0.5 , China's scores of other indicators are relatively poorer, indicating that the development of all aspects of Chinese HES is extremely uneven. As we all know, China's economic development is relatively good, and higher education funds are sufficient, so its HES has a greater potential and possibility for improvement. Considering the factors mentioned above, choose China as the object of the analysis below.

5.2. The Weak Points of the Selected Nation's Higher Education System

The calculation results of the correlation degree between indicators of Chinese HES and its health index under the 7E Framework are shown in Figure4-4. Ratio of female research personnel, No. of students in non-degree courses, and Ratio of female students exert greater influence on the health index than other indicators. These three indicators belongs to Equality and Equity, which correspond with Equity, a first-level indicator, in our Health Assessing Model. Moreover, Chinese higher education has poor performance in Equity. Therefore, equity is the weak point of Chinese HES.
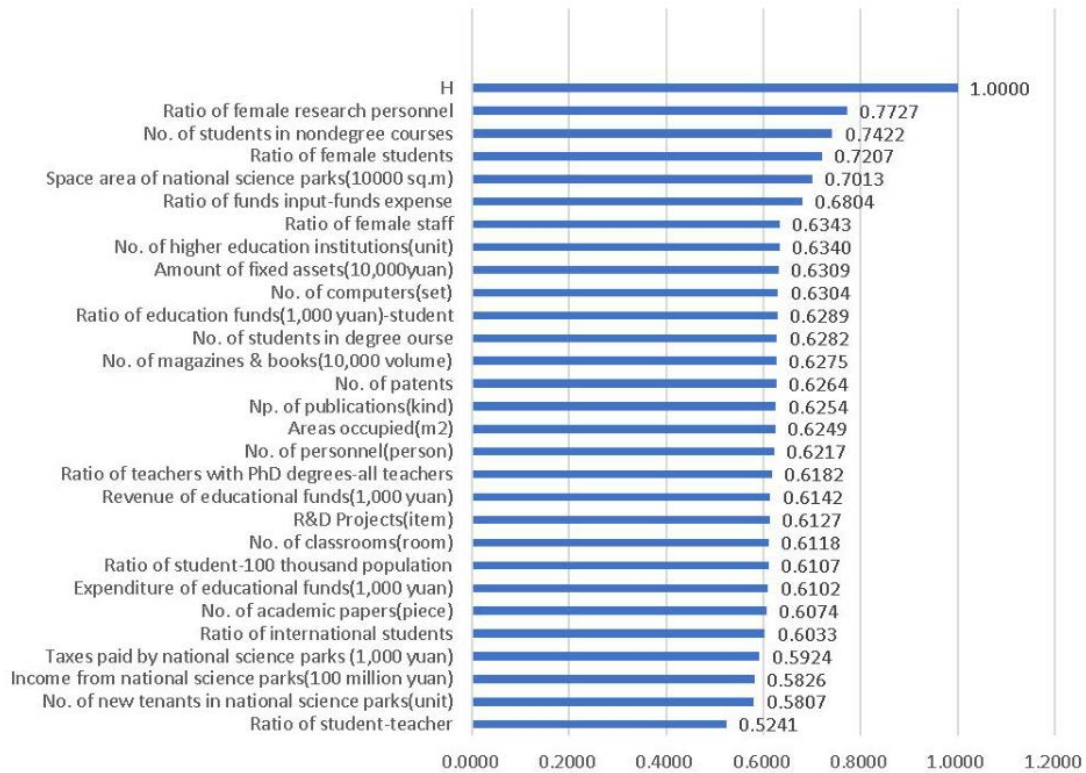
Fig. 3 Calculation results of correlation degree

6. Conclusion

In this paper, the evaluation index system and model of healthy and sustainable development with strong stability are established by using analytic hierarchy process and grey prediction model, and the higher education systems of various countries are analyzed. Taking the importance of CRITIC calculation as the basis of index comparison, the analytic hierarchy process is used to calculate the weight of the first-level index, and the comprehensive score is the health index of the national higher education system. At the same time, the 7e framework is used to construct the evaluation model of sustainable development. Then the influence degree of each index on the health of the system is obtained. Then combined with the health assessment model, the weak links of China's higher education system are analyzed.

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