Research on Global Fairness Coefficient Based on AHM-CRITIC-TOPSIS Algorithm

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Abstract: With the signing of treaties for the exploration and utilization of outer space by most countries, mankind has begun to advance the exploitation of asteroid resources. However, due to the large number of countries involved and the limited space and resources of the planets, the issue of fairness in resource exploitation is gradually emerging. Asteroid mining is a typical example. To define global fairness, analyze the national allocation of asteroid mining, with the impact of mining sector changes, and propose mining fairness policies, we construct one model to measure global equity. in order to construct a Global Fairness Coefficient (GFC) and allocate mining resources and space, we collect data of 14 indicators from 5 dimensions of 266 countries, measure the global fairness coefficient of each country based on the AHM-CRITIC-TOPSIS coupled evaluation model, and rank countries by this coefficient. Finally, countries are divided into three categories using hierarchical clustering, and mineral resources are allocated to countries by category. Among them, the United States (0.482), China (0. 452), and Japan (0.414) are the top three countries in the ranking. In conclusion, the global equity coefficient model, linear regression model of planetary mining task allocation, sectoral change impact regression model, and global mining hierarchy analysis model constructed in this paper can provide a better assessment of global equity and provide relevant policy recommendations and decision options.

Keywords: GFC; Dummy Variables; Future Situation Simulation.

1. Introduction

With the increase of population and the use of a large number of non-renewable resources, the earth's resources will be gradually exhausted in the future. As the earth could no longer provide enough energy to sustain human life, people gradually turned their attention to other planets. Many of earth's rare metals and minerals are available in large quantities in space, enough to provide a sustainable metal resource for earth's growing population[1]. The resources on the asteroid are abundant. As national technology develops and access to the resources on asteroid increases, the existing industries on earth could thrive on these resources. Asteroids are rich in water resources that could provide fuel and water for extraterrestrial exploration facilities, a cornerstone of deep space exploration[2]. In addition, the abundant resources will help scientists innovate in more application areas. So, if an asteroid that is rich in rare metal minerals is found, scientists would send unmanned spacecraft to study it if necessary[3].

The prospect of asteroid mining is promising, but the mining of asteroid minerals is quite difficult[4]. A large asteroid is easier to sample, but an asteroid smaller in width is more difficult, and such objects behave more like large space rocks, with a zero gravity field on the surface. It requires huge technical and economic support equipment to mine, dig, transport. At the same time, the cost of planetary mining robots is very high[5]. There are huge differences in development, population and technological resources among different countries. Therefore, how to allocate mining activities and mining space to achieve equity among countries is an urgent problem to be solved.

2. Assumptions

We make the following reasonable basic assumptions, each of which is properly justified.

a) Data universality and source reliability: the latest data available from World Bank is used for indicators.
b) Quantification of the system: evaluation system is quantified based on 14 indicators from 5 dimensions. Others are ignored with little importance.
c) Prioritize countries and assign quantified asteroid resources to countries according to their priorities.
d) Future asteroid mining efforts are divided into four main parts: mine, transport, pay, consume, others are ignored.
e) Do not consider some extreme conditions or external

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factors such as violent wars.

3. Global Equity System

In this Problem, we construct an evaluation system model to measure global equity and apply it to the problem of allocation of asteroid mining resources across the world. We conducted correlation analysis using AHM-CRITIC Coupling Weighting Method, and determined the weight of each indicator. Then TOPSIS is used to rank countries according to the corresponding weight of indicators, and calculate the Global Fairness Coefficient (GFC) of the evaluation system for measuring Global Equity Indicators. Finally, the mining resources should be allocated to different countries in the world through Hierarchical Clustering method. The countries are classified into high, medium and low categories.

3.1 Construction of Indicator System to Measure Global Equity

3.1.1 Chosen Indicators (5 dimensions, 14 indicators in total)

(1). Economic Dimension
Gross Income y_1 is extremely important to measure a country's development because it represents the value that producers have created for the country and society over a given period of time. A country with a high level of income means its people have a high value of production. It also means that the country is well developed and can afford the high cost of mining.
Gross Domestic Product (GDP) y_2 refers to the economic output of a country. GDP is an important indicator to measure a country's economic overall performance. It represents the prosperity degree of a country and the degree of economic welfare it provides to its people.
Tax Revenue y_3 is the main source of government revenue. Taxation affects people's enthusiasm for production and work, thus affecting the national economy. Countries with high taxes have higher economic levels.
(2). Education Dimension
Illiteracy Rate y_4 is an important factor in determining the educational level of a country. A country with a low illiteracy rate means a higher education penetration rate. Education helps lift the poor out of poverty, increases the value and efficiency of labor, and is key to improve economic efficiency and social coherence[6].
Labor Force with Advanced Education y_5 represents the development of national higher education level. It also represents the high value of labor and efficiency of national production and life[7].
(3). Resources Dimension
Arable Land y_6 is an important resource factor. Arable land can produce more food, reducing hunger and reducing food imports. The country with large arable land is self-sufficient, more politically independent and has a better level of development[8].
Labor Force y_7 can be used to measure the efficiency of inputs and outputs in a production process. A large workforce is based on a large resource base. Thus, labor can represent the ownership of resources.
Population growth rate y_8 determines the change and demand of resources in a certain period of time in the future. Therefore, countries with high population growth rates need more potential resources to meet the resource benefits of mining.
Electricity generated from oil et al. y_9 represents the oil abundance and energy conversion efficiency of a country. Electricity generated from oil et al. resources can measure the development of a country.
Renewable Energy y_{10} represents the country's sustainable resources that can support the production and industry need of the country, which can reflect the country development level [9].
(4). Medical Level Dimension
The creditability and development of the national medical system can be measured by the number of skilled health staff y_{11}during the childbirth process. Better care for the baby born process reflects a more developed country with better health care.
ARI Treatment (% of Children Under 5 Taken to Health Provider) y_{12} represents the treatment rate of infants and young children, which can be used to measure the level of medical care in a country.
Current health expenditure y_{13} represents to some extent the level of development maturity of the country. Developed countries have relatively more health expenditure, so they have a very complete medical system and health system [10].
(5). Technology Dimension
High technology experts y_{14} can measure the current level of science and technology in the country and its potential for development. Figure 1 below is the schematic diagram of indicator and dimension relationship.

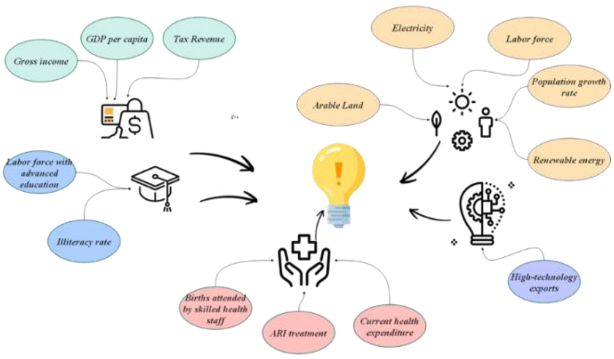


Figure 1. Schematic Diagram of Indicator and Dimension Relationship

3.1.2 Weight Calculation and Correlation Analysis

We adopt AHM-CRITIC Coupling Weighting Method and carry out correlation analysis of the above-mentioned indicators. Combining subjective weighting of AHM with objective weighting of CRITIC makes up the defects of single weighting, and constructs AHM-CRITIC coupling weighting mechanism. Under this mechanism, indicators with higher relative weight contribute more to the GFC, and vice versa.

(1). Processing of Data

In order to make the obtained data easy to identify and analyze, we need to preprocess and standardize the data. We divide our indicators into positive and negative indicators. The positive indicator means that the larger the value of this indicator is, the more resources a country may be allocated. Otherwise, it has a negative impact on the evaluation the country's priority, thus a negative indicator. In our 14 indicators, except illiteracy rate, all are positive indicators. We can standardize positive and negative indicator data by the following formula where $j = 1,2,3,\ldots,n$, x_{ij} is standard value in the evaluation index, y_j is indicator:

$$Positive\ standard:\ x_{ij} = \frac{y_{ij} - min(y_j)}{max(y_j) - min(y_j)} \quad (1)$$

$$negative\ standard:\ x_{ij}' = \frac{-y_{ij} - min(y_j)}{max(y_j) - min(y_j)} \quad (2)$$

(2). AHM Method

AHM method can effectively assign subjective weights. Decision making with AHM can be roughly divided into three steps:

Step 1. Establish hierarchical structure and determine the weight of indicators

Before establishing the attribute discriminant matrix, we first need to determine the scale of the relative importance of each evaluation index. Here, we mainly refer to Saaty scale to assign values to the elements in attribute matrix, and construct n-dimensional AHP (analytic hierarchy process) discriminant matrix by global expert scoring K=k_{ij}, where k_{ij} represents the importance of element i compared with element j. The discriminant matrix K has the following properties: k_{ii}=0 and k_{ij} >0.

Step 2. Construct judgment matrix

In AHM, the relative attribute l_{ij} constitutes the n-dimensional attribute discriminant matrix L=l_{ij}, and the relation between relative attribute $l_{ij}$and scale k_{ij}can be transformed as follows

$$l_{ij} = \begin{cases} \dfrac{2m}{2m+1}, & k_{ij} = m, i \neq j \\ \dfrac{1}{2m}, k_{ij} = \dfrac{1}{m}, i \neq j \end{cases} \quad (3)$$

$$l_{ij} = \begin{cases} 0.5, & k_{ij} = 1, i \neq j \\ 0, & k_{ij} = 1, i = j \end{cases} \quad (4)$$

Step 3. Calculate relative attribute weight of each indicator to the system target

We can calculate the relative attribute weight of each index W_{AHM}, n indicates the number of indicators.

$$W_{AHM} = \frac{2}{n(n-1)} \sum_{j=1}^{n} l_{ij} \quad (5)$$

(3). CRITIC Method

CRITIC method [11] is an objective weight assignment method proposed by Diakoulaki. It is based on the contrast intensity and conflict between evaluation index to determine the objective weight of indicators. This method can be roughly divided into three steps:

Step 1. Calculate standard deviation. $\bar{x}_j$ is the average value of index X_j in m schemes; σ_j is the standard deviation of X_j

$$\sigma_j = \sqrt{\frac{1}{m-1} \sum_{i=1}^{m} (x_{ij} - \bar{x}_j)^2} \quad (6)$$

Step 2. Construct correlation coefficient matrix. $\bar{x}_i$ is the average value of all indexes in index X_i; $\bar{x}_j$is the average value of all schemes in index X_j; r_{ij} is the correlation coefficient of indexes X_i and X_j

$$r_{ij} = \frac{\sum_{i=1}^{n} (x_i - \bar{x}_i)(x_j - \bar{x}_j)}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x}_i)^2 (x_j - \bar{x}_j)^2}} \quad (7)$$

Step 3. Find the comprehensive weight of indicators W_{CRI}

$$W_{CRI} = \begin{cases} W_{CRI} = \dfrac{C_j}{\sum_{i=1}^{n} C_j} \\ C_j = \sigma_j \sum_{j=1}^{n} (1 - r_{ij}) \end{cases} \quad (8)$$

(4). Coupling weight calculation -- Lagrange multiplier optimization method

According to (5) and (8), we can obtain subjective weight W_{AHM} and objective weight W_{CRI}. Then the combination weight can be calculated by using Lagrange multiplier optimization method. According to the principle of minimum relative entropy, the Lagrange multiplier optimization method can optimize the algorithm to the maximum extent, and can effectively reflect the relative weight relationship of each index and its weight proportion in the whole:

$$W_{AHM-CRI} = \frac{(W_{CRI} W_{AHM})^{0.5}}{\sum_{j=1}^{n} (W_{CRI} W_{AHM})^{0.5}} \quad (9)$$

3.1.3 Solution of Global Fairness Coefficient (GFC)

We have captured the importance of each indicator to measure the overall strength of each country. We want to quantify this as GFC that represents the proportion of resources that a country should be allocated. Therefore, we use TOPSIS method to sort. The relative proximity results of TOSIS is the GFC we seek. By comparing the Euclidean distance between different evaluation objects, TOPSIS sorts them in order to judge their merits and demerits. The results can fully reflect the gap between evaluation schemes and obtain comparable evaluation ranking results. The steps are as follows:

Step 1. Trend the evaluation indicators

The same trend requires that all indicators change in the same direction, which means high-excellent indicators are transformed into low-excellent indicators or low-excellent indicators are transformed into high-excellent indicators.

Step 2. Normalize with trend data and construct standard weighted matrix.

The standard weighted matrix Z= z_{ij} is constructed by coupling weights with assimilation matrix Y. W_j is the coupling weight of each index, and y_{ij} is the normalized value.

$$z_{ij}=W_j * y_{ij}. \quad (10)$$

Step 3. Determine the positive and negative ideal solutions

According to the weighted matrix, the positive and negative ideal solutions of indicators are determined. The positive ideal solution set is $K^+ = (k_1^+, k_2^+, \ldots, k_n^+)$. The larger the value, the better; The negative ideal solution set is $K^- = (k_1^-, k_2^-, \ldots, k_n^-)$. The smaller the value, the better.

Step 4. Calculate the approximation degree C of each solution to the optimal solution.

According to Euclidean distance, the distance between each solution with positive and negative ideal solution D_i^+ and D_i^- are evaluated

$$\begin{cases} D_i^+ = \sqrt{\sum_{j=1}^{n}(z_{ij} - z_j^+)^2} \\ D_i^- = \sqrt{\sum_{j=1}^{n}(z_{ij} - z_j^+)^2} \end{cases} \quad (11)$$

So proximity C can be calculated by the formula above

$$C_i = \frac{D_i^-}{D_i^- + D_i^+} \quad (12)$$

The greater the degree of closeness is, the better the solution is.

Step 5. Determine the optimal solution According to the degree of proximity, the evaluation objects are sorted from high to low, and the optimal solution is finally obtained according to the relative relationship of the degree of proximity. The combined weight is proximity degree C.

3.1.4 Calculation principle of equity coefficient GFC

As 14 indicators in the five dimensions are affected by other factors, it is difficult to achieve comparison directly through coupling weights and rankings. Therefore, we adopt the variational coefficient method (CVM) to solve the comprehensive weight. Five dimensions are recorded as EDU (education), ECO (economy), RES (resources), MED (medical care) and TEC (technology respectively). After the 14 indicators are expressed as 5 comprehensive variables, the coefficient of variation method is used to weight the 5 coefficients of this level and further aggregated into a comprehensive measure index (GFC) to measure global equity.

Coefficient of variation method (CVM) is to use the comprehensive information of each indicator and calculate the weight of each indicator. The formula of each indicator can be expressed as:

$$A_i = \frac{\theta_i}{Z_i} \quad (13)$$

A_i is the variation coefficient of indicator i, θ_i is the standard deviation of indicator i, and Z_i stands for TEC, RES, ECO, EDU and MED. Then, we can calculate the weight of five comprehensive indicators:

$$W_{net\ i} = \frac{A_i}{\sum_{i=1}^{n} A_i} \quad (14)$$

$i = 1, 2, \ldots, n$. To sum up, we can calculate the weight of each indicator (labeled as $W_{net\ 1}$, $W_{net\ 2}$, $W_{net\ 3}$, $W_{net\ 4}$, $W_{net\ 5}$). Then, based on these calculated weights, we can get the fairness coefficient (GFC).

$$GFC = (TEC * W_{net\ 1} + RES * W_{net\ 2} + \ldots + MED * W_{net\ 5}) \times 100 \quad (15)$$

Note: According to the AHM-CHRTIC coupling weighting method in the second step, we can know that the measurement indicators TEC, RES, ECO, EDU and MED of five dimensions are formed by the variation of each indicator under this dimension according to the weight coefficient. Namely.

$$TEC = W_1 x_{1j} \quad (16)$$

$$RES = W_2 x_{4j} + W_3 x_{3j} + W_4 x_{4j} + W_5 x_{5j} + W_6 x_{6j} \quad (17)$$

$$ECO = W_7 x_{7j} + W_8 x_{8j} + W_9 x_{9j} \quad (18)$$

$$EDU = W_{10} x_{10j} + W_{11} x_{11j} \quad (19)$$

$$MED = W_{12} x_{12j} + W_{13} x_{13j} + W_{14} x_{14j} \quad (20)$$

Where W_i is the coupling weight coefficient, x_{ij} is the ith index. At the same time, according to step 3, we can know that the degree of closeness obtained by sorting C is our $W_{net\ i}$.The GFC we calculated for all countries is in Appendix 1.

3.1.5 Clustering Analysis

For the sake of presentation, we have selected the top 20 countries out of 226. Through the previous four steps, we can obtain GFC of each country. Here, we mainly adopt the hierarchical clustering method to quantify into three levels.

Step 1. We create an n-dimensional distance matrix *X*. Record each data point as d_i, and merge the data points with the smallest distance to obtain a combined data point.

Step 2. Calculate the distance between the data points and the combined data points

Step 3. Realize the distance between the combined data points and the combined data points by the algorithm of Average Linkage.

3.2 Results Visualization

The subjective weight W_{AHM} objective weight W_{CRI} and the coupling weight $W_{AHM-CRI}$ are shown in Figure 2.

From the result of coupling weight, the tax weight in the economic field is the largest, which has a greater impact on the economic level. Labor Force has the greatest impact in Education, while renewable energy has the greatest impact in resources. The three indicators of health care have a certain degree of influence. There is only one indicator for technology, no correlation analysis. The specific weights are shown in Figure 3.

	Indicators	Weight-AHM	Weight-CRITIC	Weight-AHM-CRITIC
Economics	Gross Income	0.05350	0.01526	0.04299
	GDP	0.08818	0.00414	0.05770
	Tax Revenue	0.05830	0.18039	0.14930
Education	Literacy rate	0.05714	0.02214	0.04956
	Labor force with advanced education	0.14286	0.17765	0.20044
Resources	Arable land	0.01602	0.06713	0.05201
	Labor force	0.02646	0.00943	0.02244
	Population growth rate	0.01728	0.05400	0.04459
	Electricity generated from oil et al	0.07396	0.00729	0.05079
	Renewable energy	0.06628	0.06301	0.08085
Medical care	Births attended by skilled health staff	0.03140	0.10631	0.08614
	ARI treatment (% of children under 5 taken to health provider)	0.03804	0.08713	0.07829
	Current health expenditure	0.13058	0.00635	0.08559
Technology	High technology experts	0.20000	0.19978	0.25000

Figure 2. Weights for Countries

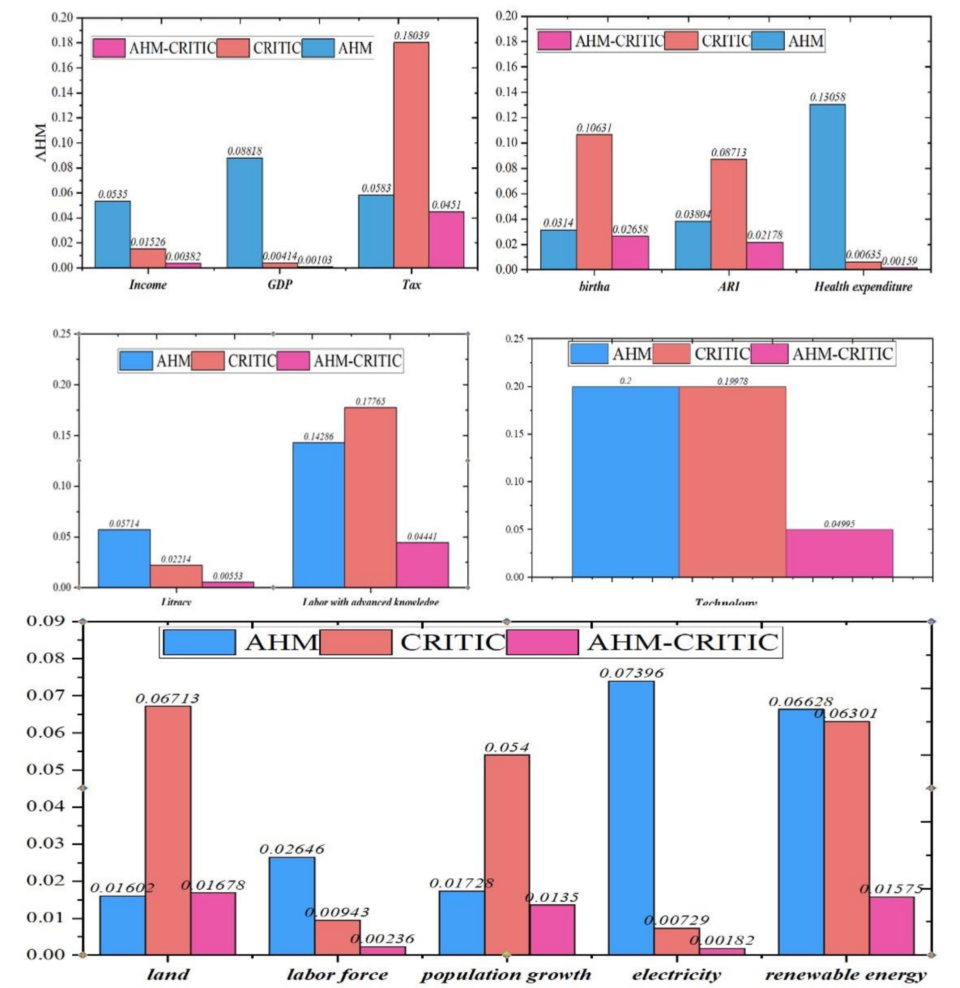
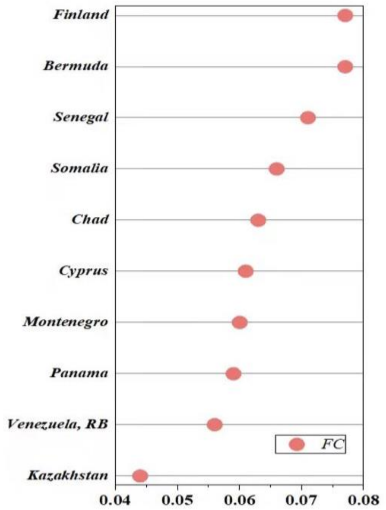


Figure 3. Weight result graph under different methods

Figure 2 shows the ranking of the 20 countries with GFC from highest to lowest (top 1-10 on the left and bottom 1-10 on the right). In order to ensure that the evaluation system we construct can well reflect global equity, we allocate resources according to GFC. The higher the GFC score of the country, the more resources can be allocated.

(a) top ten countries



(b) last ten countries

Figure 4. Relative proximity of countries GFC

We can see the top 10 countries and the bottom 10 countries in terms of fairness. We can find that its fairness coefficient can basically represent the current national development level. In addition, our model is divided into five levels, which can truthfully reflect the comprehensive strength of a country, such as its education level, medical level and scientific and technological level. Taking the United States as an example, its fairness coefficient is 0.482, ranking first in the world, which is basically consistent with its development level in the world[12]. Take Montenegro, which is in the bottom ten, its fairness coefficient is 0.06. The GDP of Montenegro[13]in 2020 is far smaller than that of the United States at the same time, and its technological development level is also backward, which is consistent with the results of our model. Overall, the top 10 countries are mainly concentrated in East Asia, North America, Europe. The bottom ten are clustered in regions such as Africa. The main reason is that the top 10 countries are located in a geographical location with abundant resources, convenient transportation and suitable climate for production activities. In addition, the development of continental Europe is relatively earlier, and their technology is far ahead [14]. We can conclude that it is reasonable to allocate resources according to the GFC generated by our model. Figure 5 shows the TOPSIS ranking results. The darker the blue color, the higher the ranking.

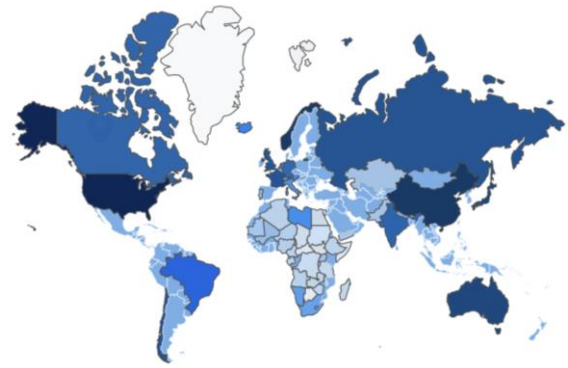


Figure 5. Countries Ranking Results from TOPSIS Model

Next, we conduct a hierarchical cluster analysis on GFC, and divide the 20 countries into three different priorities.

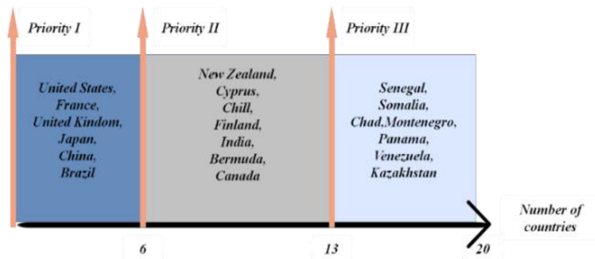


Figure 6. Countries divided into 3 categories

According to the Figure 6, We divide the above twenty countries into three categories of priorities. United States, France, United Kingdom, Japan, China, Brazil is a priority country of Category I, and can be allocated mineral resources to the greatest extent; New Zealand, Cyprus, Chill, Finland, India, Bermuda, Canada)is Category II, and Senegal, Somalia, Chad, Montenegro, Panama, Venezuela, Kazakhstan is Category III. The allocated mineral resources gradually decrease with category level.

3.3 Model Validation

We conduct correlation analysis on fourteen indicators from five dimensions.

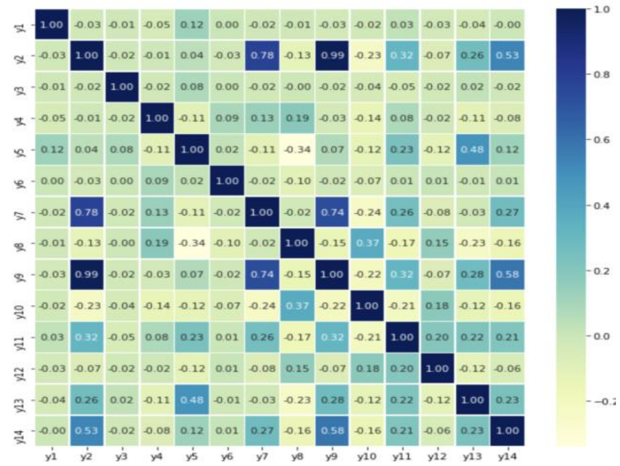


Figure 7. The correlation matrix of standardized data

Each value in Figure 7 is generated by the correlation matrix. It can be seen that the color of most data is relatively light and the correlation coefficient close to 0, indicating that the correlation between corresponding variables is low. This further verifies that our variables can be regarded as independent indicators, which indicates that our model meets the independence test and the results given are reliable and accurate.

4. Conclusion

In order to solve the global equity problem caused by asteroid mining, we first formed 14 indicators from 5 different dimensions, assigned corresponding weights to each indicator by AHM-CRITIC method, and used TOPSIS method to transform indicators into Global Fairness Coefficient (GFC) to rank the 266 countries. Finally, the hierarchical clustering method was used to divide countries into different categories according to GFC, then the asteroid mineral resources can be allocated to the countries according to the categories. Therefore, we successfully constructed a model to measure the GFC.

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