

The Vision for the Future of Asteroid Mining

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Abstract: In recent years, the contradictions between various energy problems, environmental problems and human development have become more and more intensive, and the imbalance distribution of natural resources in various countries has become severe. In order to address these problems, the concept of asteroid mining came into being, which brings people the hope of obtaining resources from outer space. In this paper, we model global equity in the context of asteroid mining, and ask how people's lives could be improved. What will happen to the fairness of the world? First, in order to build a model to measure global equity, we select some indicators according to Maslow's Hierarchy of human needs theory, including happy-planet-index, youth employment rate, life expectancy, infant mortality rate, and the proportion of female students to male students in higher education in 2021 of eight zones to construct the EWM-TOPSIS model, results illustrate that UK is the most unfair country and Japan is the fairest country. The equity indexes is classified into three levels, and are used to achieve the clustering of the fairness degree of each country in the world. Second, we describe the current status of asteroid mining, and realize that although the asteroid mining project is developing rapidly at the technical level, there is still a lack of global unified regulation and constraints at the institutional level. On this basis, we design a mature and complete global asteroid mining system, and envision the distribution of the mined resources according to the nature endowments.

Keywords: EWM-TOPSIS model; clustering; global equity; asteroid mining.

1. Introduction

1.1 Literature Review

In terms of the analysis of global equity, Jingzhu Gao (2019)[1] concluded that global governance is an important mechanism to achieve global equity by analyzing the path to achieve global justice. As for the possibility of asteroid mining, Chengbo Qiu et al. (2019)[2] summarized the future planetary defense and mining technologies of the United States, Japan and other countries, which provided technical support for our design model of asteroid mining.

It is pointed out in literature [3] that in 2015, President Obama signed the Commercial Space Launch Competition Act of the United States, which marks the birth of the first legislation on space mining, entrusting space mining with legality and providing legal guarantee for private enterprises to exploit space resources and conduct commercial use. Currently, many scholars have studied the status quo, development and challenges of space mining. Chengbo Qiu, Yamin Wang et al. (2019) [4] reviewed the exploration history of near-earth asteroids, focusing on the planetary defense plans of OSIRIS-Rex, NASA, ESA, as well as the commercial mining strategy planning of asteroid mining companies, and pointed out that developed countries are becoming more mature for near-earth asteroid detection technology. In the future, more attention should be paid to in-depth sampling and planetary defense. Kefei Zhang, Huaizhan Li et al. (2020) [5], based on the introduction of the development status of space mining, described the mining targets of space resources, by analyzing the feasibility of developing and utilizing space resources, and finally suggested that the most suitable mining target is near-Earth asteroid.

Combing the literatures above, the fair idea about global governance system is of great significance, and many scholars based on Mars's carbon dioxide and water resources utilization, studied near-earth asteroids detection technology and space mining, further analyzing the possibility of obtaining space resources in the form of asteroid mining. The Outer Space Treaty, signed by the United Nations in 1967, allows the utilization of outer space for the improvement of mankind, for the purpose of

contributing to global equity. However, when nations seek space resources, it is likely to undermine international commitments to equity. Based on this problem, this paper analyzes the influencing factors and mechanisms of asteroid mining on global equity, and puts forward relevant suggestions for the United Nations to improve global equity.

Our work are summarize as follow:

Explicit and definite the notion of 'global equity', and select some indicators which could measure global equity, establishing EWM-TOPSIS Model to measure the extent of global equity.

Introduce, describe and justify the vision for asteroid mining, and analyze the effect of asteroid mining to global equity.

2. Global Equity Model

2.1 Model Preparation

To measure global equity, we first consider the definition of equity. Equity refers to the pursuit of the justice quality, we sorted out relevant literature and laws, finding that for pros and cons of groups, equality seeks to have similar resources and opportunities, while fairness seeks to make everyone reach a similar level by allocating resources and opportunities.

On the basis of our understanding of equity theory, we select happy-planet-index, youth employment rate, life expectancy, infant mortality rate, and the proportion of female students to male students in higher education as indicators to measure global equity. In order to quantitatively obtain the influence degree of those indicators, we adapt the entropy weighting method to this issue.

2.2 Entropy Weight Method Model (EWM)

Entropy is a concept in information theory, which is the measure of uncertainty.

As the dispersion degree become larger, the uncertainty degree and the entropy value become smaller conversely.[9].The smaller the entropy value, the greater the dispersion degree of the indicator, and the greater the influence (i.e., weight) of the indicator on the comprehensive evaluation.

Step 1: Gather the values of i countries (including China, US, UK, EU, India, Brazil, Japan and Russia.) on j indicators. The indicators include happy-planet-index, youth employment rate, life expectancy, infant mortality rate, and the proportion of female students to male students in higher education. ($i = 1, 2 \dots 8; j = 1, 2, 3, 4, 5$)

Step 2: Data preparation

$$\text{For positive data } x_{ij}' = \frac{x_{ij} - \min(x_{1j}, \dots, x_{nj})}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \quad (1)$$

$$\text{For negative data } x_{ij}' = \frac{\max(x_{1j}, \dots, x_{nj}) - x_{ij}}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \quad (2)$$

Step 3: Calculate the percentage of the i^{th} country under the j^{th} index.

$$p_{ij} = \frac{x_{ij}'}{\sum_{i=1}^n x_{ij}'}, i = 1, \dots, n; j = 1, \dots, m \quad (3)$$

Step 4: Calculate the entropy value of the j^{th} indicator.

$$e_{ij} = -k \sum_{i=1}^n p_{ij} \ln(p_{ij}) \quad (4)$$

$$k = \frac{1}{\ln(n)} \tag{5}$$

Step 5: Calculate the redundancy value of the J^{th} indicator.

$$d_j = 1 - e_j \tag{6}$$

Step 6: Calculate the weights of each indicator.

$$w_j = \frac{d_j}{\sum_{j=1}^m d_j} \tag{7}$$

Step 7: Analyze the effect of each indicator on global equity according to the results of weight calculation[10]. The calculated weight can be used in TOPSIS.

2.3 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)

Step 1: Data preparation.

For positive indicator (happy-planet-index, youth employment rate, life expectancy):

$$Z_{ij}^+ = \frac{x_{ij} - \min(x_{1j}, \dots, x_{nj})}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \tag{8}$$

For negative indicator(infant mortality rate, the proportion of female students to male students in higher education):

$$Z_{ij}^- = \frac{\max(x_{1j}, \dots, x_{nj}) - x_{ij}}{\max(x_{1j}, \dots, x_{nj}) - \min(x_{1j}, \dots, x_{nj})} \tag{9}$$

Step 2: Figure out the optimal and inferior matrix vectors.

$$Z^+ = (\max Z_{i1}, \max Z_{i2}, \dots, \max Z_{im}) \tag{10}$$

$$Z^- = (\min Z_{i1}, \min Z_{i2}, \dots, \min Z_{im}) \tag{11}$$

Step 3: Calculate the distance between the evaluation object and the positive ideal solution D_i^+ or the negative ideal solution D_i^- .

$$D_i^+ = \sqrt{\sum_{j=1}^m w_j (\max Z_{ij} - Z_{ij})^2} \tag{12}$$

$$D_i^- = \sqrt{\sum_{j=1}^m w_j (\min Z_{ij} - Z_{ij})^2} \tag{13}$$

Step 4: G_i are the integrated global equity index of these countries.

$$G_i = \frac{D_i^-}{D_i^+ + D_i^-} \quad 0 \leq G_i \leq 1 \tag{14}$$

G_i takes values from 0 to 1, dividing the intervals into multiple levels equidistantly, and thus determining the most fair and the least fair countries[11].

2.4 Data preparation: Min-Max Standardization

Brazil, China, EU, United Kingdom, India, Japan, Russia and United States was selected as representatives on a global scale, then we measure global fairness by analyzing a series of their indicators in 2021. The specific variables are as follows.

Table 1: Overview of Equity Indicators

Country	Employment rate/percent	Child mortality/per 1000 born	Life expectancy/year	The ratio of female to male in school/percent	Happy planet index
Brazil	41	13.9	76.4	113	45.6
India	20.8	8.34	78.1	89.2	51.5
Russia	27.3	3.46	81.7	102	43.8
China	40.5	4.24	81.4	102	50.3
UK	50.1	35.2	71.5	67.9	52.3
Japan	47	2.41	85.2	102	56.1
US	48	6.81	73.4	105	39.7
EU	48.4	6.58	79.1	103	35.1

The Happy Planet Index (HPI) is a measure of sustainable well-being. Equation 1 illustrates, how HPI scores are calculated approximately. [1] It can be calculated by the following equation:

$$\text{Happy Planet Index} = \frac{\text{life expectancy} * \text{experienced well-being}}{\text{ecological footprint}} \quad (15)$$

Before calculating the weights with the EWM Model, the data are min-max normalized by applying equations (8) and (9). The indicator of child mortality is negative and ought to be orthogonalized by substituting the data into (9) to make the normalized variables positive. For the rest indicators, they are positive data, and these data are normalized by substituting them into (8) respectively. The variables after the convergence treatment are not affected by the difference of the magnitude, and the data size can be compared at the same level, which makes the calculation of the weights practically meaningful, i.e., the global equity can be analyzed by comparing the weight size.

2.5 Data Processing

After data pre-processing, the entropy weight method is used to calculate the weights of each indicators, so as to measure the global equity extent.

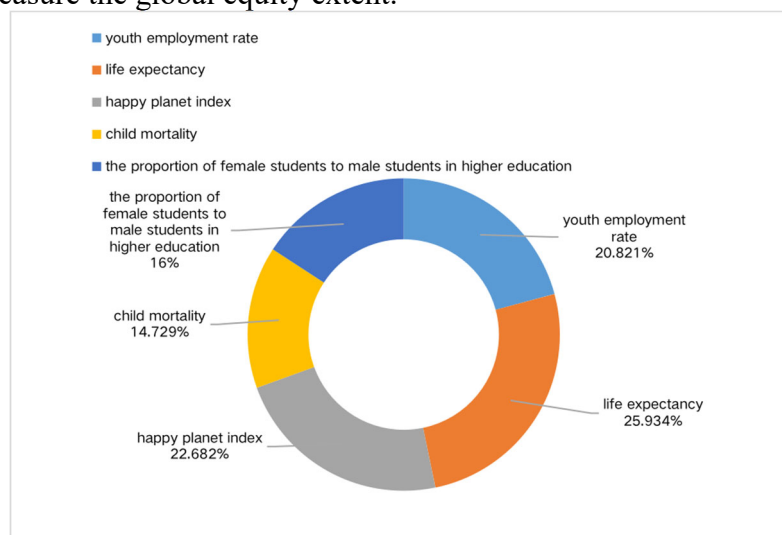


Figure 1: The Importance of Indicators

The weight calculation results of the entropy weight method indicate that the weight of employment rate is 20.821%, the weight of life expectancy is 25.934%, the weight of the ratio of female to male in school is 16%, the weight of happy planet index is 22.682%, and the weight of child mortality is 14.729%, where the maximum index weight is life expectancy (25.934%) while the minimum is child mortality (14.729%).

Table 2: Positive and Negative Ideal Solution

item	Positive ideal solution	Negative ideal solution
Employment rate	0.47008552	0.0000016
Child mortality	0.60154677	0.00000439
Life expectancy	0.48676295	0.00000108
The ratio of female to male in school	0.55264211	0.00000263
Happy planet index	0.42902593	0.00000131

Positive and negative ideal solutions (non-distance) respectively represent the maximum or minimum values of the evaluation index (i.e., optimal and inferior solutions). Using equations (10) and (11), the optimal and inferior matrix vectors can be determined, i.e., the optimal matrix vector $Z^+ = (0.47, 0.60, 0.49, 0.55, 0.43)$; the inferior matrix vector $Z^- = (0.0000016, 0.00000439, 0.00000108, 0.00000263, 0.00000131)$.

Table 3: Sorting Results

Country	Positive ideal distance (D+)	Negative ideal distance (D-)	Equity index	Rank
Brazil	0.2525948	0.31646195	0.55611668	4
India	0.29304089	0.30097786	0.50668074	6
Russia	0.24496893	0.33618797	0.57848056	3
China	0.1405686	0.38950215	0.73481163	2
UK	0.40092165	0.30410715	0.43134004	8
Japan	0.05241052	0.49846058	0.90485883	1
US	0.3373004	0.30081672	0.47141302	7
EU	0.30052466	0.33627829	0.52807276	5

Using equations (12) and (13), we can obtain the positive ideal solution distance D^+ and negative ideal solution distance D^- . The smallest value of D^+ in Japan shows that it is the closest to the optimal solution; the smallest value of D^- in UK indicates that it is the closest to the worst solution. Using equation (14), we are capable of calculating the integrate score C value for each country. The C value in UK is the smallest and ranks the last, while in Japan it is the largest and ranks the first.

2.6 Results Analysis

According to the calculation results of the entropy weighting method, the influence degree of different indicators on measuring the global equity can be obtained. The weight of life expectancy is the largest, illustrating that life expectancy has the greatest impact on determining the global equity; while the child mortality is the smallest, indicating that it does not have much impact on determining the global equity. After establishing the importance of different indicators, the equity of different countries is considered as the evaluation object and analyzed by TOPSIS. Comparing the integrate score index of each country, we find that it is the highest in Japan and the lowest in UK. From the ranking results, it is evident that UK is the most unfair country and the fairest country is Japan in 2021.

In order to generalize the comprehensive evaluation model established by eight countries to a global scale and obtain global equity scores in different regions by applying this model, we divide the fairness of different countries into different levels according to the above comprehensive score results, so as to achieve the goal of Clustering of fairness in different countries around the world.

Table 4: Schematic Diagram of Comprehensive Evaluation Level

Threshold for equity indicator	Integrate score index
Poor	< 0.3
Ok	[0.3, 0.6)
Good	≥ 0.6

According to established EWM-TOPSIS model, the comprehensive fairness scores of different countries can be obtained, so that the global fairness can be measured by the corresponding fairness index threshold.

3. A Vision for Asteroid Mining

3.1 The state of asteroid mining

Asteroid mining is just one part of the asteroid redirection plan, a blueprint for the efficient use of space resources. Although the plan does not currently allow us to reap significant benefits from asteroid mining, using space resources could be an important precursor to large-scale asteroid mining to supply earth's limited resources.

3.2 Vision for the future of asteroid mining

Based on this, assuming that the technology is complete, we envision an institutional vision for future asteroid mining.

The Outer Space Treaty, the current legal regime of the United Nations in outer space, does not explicitly prohibit the exploration of minerals outside the earth and regulate the ownership of the mineral resources mined. However, it adheres to the principle of "commercial aviation, law comes first", and the international community must establish mutually accepted international rules in this regard.

First, we need to ensure the safe and sustainable development of space resources. The understanding of outer space is still limited, and the assessment of risks are not systematic and comprehensive. Therefore, the utilization of outer space resources should be discussed by scientists of all countries in a reasonable and controllable way, as well as other technical and ethical limits.

Secondly, it is necessary to clearly divide the main body functions involved in this activity, and then achieve reasonable distribution. Since this activity is for the well-being of all mankind and not driven by the interests of any enterprise or country, a relatively reasonable model should be as follows: Governments of all countries invest in accordance with their factor endowments, pool resources and set up an organization supervised and managed by the United Nations. Eventually mining income and resources first distributed by the United Nations according to the primary factors, then all countries secondary distribute resources to all parts in the domestic involving people work for the project and the masses of the people that does not participate in the project, aiming to make people of all countries can gain more resources than before and to encourage professional and technique personnel further utilize their expertise within the project.

Therefore, the ideal organizational structure of the mining sector should be "global participation, tripartite restriction".

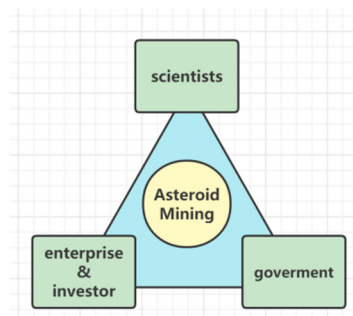


Figure 2 : The Ideal Organizational Structure of Asteroid Mining

Scientists are undoubtedly the most important link. They are the messengers between the government and enterprises, they should inform both sides of the difficulties faced by enterprises and the risks faced by the government; Meanwhile, they should also provide technical guidance to help enterprises overcome the technical problems they encounter as much as possible, so they should always be the party with the most benefits. The second part is the government and people representatives. They are the leaders who set the main tone, make important decisions, coordinate important work and represent the interests of the people. Therefore, the allocation of resources should also give important consideration to this party for our original intention is to improve the distribution of resources for all mankind. Finally, there are enterprises and companies with related technologies. Generally speaking, the driving force of enterprises and companies is to maximize profits, but here, the situation is a bit special. Most of their funds for operating the project come from government departments, and the government's purpose is essential to improve the efficiency of work and the speed of technological iteration. Therefore, the main source of income of the enterprise part should not be the resources they mined, but should be other related business while mining asteroids, such as open live channels to popularize science to the public, or make some handicrafts from a small amount of mined materials, they should strengthen the concept of outer space to increase their added value, and finally obtain higher profits. Enterprises should negotiate with the government and sign an agreement on "the freedom of activities of enterprises in outer space", so that enterprises can develop existing businesses within a certain limit, which is also conducive to increasing the enthusiasm of enterprises for research and development.

4. Conclusion

In conclusion, firstly, we definite the notion of 'global equity' according to Maslow's Hierarchy of Human Needs theory, and select some indicators which could measure global equity, including the happy-planet-index, youth employment rate, life expectancy, infant mortality rate, and the proportion of female students to male students in higher education in 2021 of eight zones, establishing EWM-TOPSIS Model to measure the extent of global equity. It turns out that Japan is the fairest country, and the United Kingdom is the opposite. We divide the equity index into three degrees and apply them to realize the clustering of the fairness in countries around the world. Secondly, we introduce, describe and justify the vision for asteroid mining, and analyze the effect of asteroid mining to global equity. The asteroid mining project is developing rapidly and technically, but still lacks of global unified regulation and constraints at the institutional level. Thus, we envisage what future asteroid mining will be and deduce the optimal organizational structure of the mining sector should be "global participation, tripartite restriction".

When we select measurement indicators, we combine objective factors such as medical level, education and employment rate with subjective factors such as happiness, making the meaning of fairness more universal. In addition, we selected eight regions with significant differences as the subjects of analysis. The differences make them highly representative, help portray the global situation, have strong relevance, and make the analysis results applicable. However, When looking for indicators to measure fairness, although the scope is relatively comprehensive, only one indicator "happiness" that can reflect people's subjective opinions, which may not be convincing enough and cause the results to deviate from reality. What's more, although we prefer the calculation to be as accurate as possible, owing to the long number of decimal places in the data we used, we had to round off some of the decimals.

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