

Mine World, Mine Equity

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Abstract. As asteroid mining projects break through the technical barriers, more countries have the plan to become mining pioneers. However, the world currently does not have a complete policy to ensure that asteroid mining can benefit all of humanity. Therefore, exploring its fairness and normality needs to be on the agenda. AHP and EWM are used to construct a global fair distribution model that is more in line with "global interests." It is defined as "global fairness" from the perspectives of the same right to enjoy resources. Moreover, it also guarantees the interests of each country, which maximizes global interests and lays the foundation for the subsequent investigation of the impact of an asteroid mining plan on global fairness. Based on the foundation of the model, the fact is also considered that asteroid mining is currently in the early stage of research and development, which faces the situation of high investment risk and unpredictable returns. To mobilize the enthusiasm of the majority of countries, the different contributions of different countries need to be considered in the construction of the allocation model. Then, a multidimensional index analysis model is established through GRA, which redefines global equity from two dimensions of fairness and contribution.

Keywords: Asteroid Mining, Global Equity, Space Policy, Analytic Hierarchy Process, Entropy method, Grey Relational Analysis, Principal Component Analysis.

1. Introduction

As Stephen Hawking predicted, "Within the next hundred years, humans have to leave Earth and go to space to find a new home to survive." Asteroid mining programs, extracting minerals from asteroids for human use, are becoming a reality. More and more scholars are studying their technical and economic feasibility and legal rationale. Meanwhile, companies, such as Planetary Resources and Deep Space industries, have emerged to make commercial attempts.

In 1967, 104 countries signed the Outer Space Treaty, and it is agreed that "the exploration and use of outer space, including the Moon and other celestial bodies, shall be for the benefit of all nations, irrespective of their degree of economic or scientific development. It shall be the province of all humankind." As an international commitment, the treaty provides a juridical basis for equitable exploration of space by all humankind.

However, for a long time, the legality of unilateral exploration and utilization of natural resources in outer space by states or private, non-governmental entities has been one of the hot issues of controversy in the international community. Especially in recent years, the introduction of bills allow private commercial exploitation and utilization of space resources by countries, which represented by the United States and Luxembourg. It has aroused heated debates in the international community, which implies that the pursuit of space resources utilization to all humankind in the process. It means that the two concepts of absolute equity and relative equity of rights in the pursuit of space resource utilization are in strong conflict, and the pursuit of both values has its advantages and disadvantages, which is worth exploring. Meanwhile, asteroid mining will inevitably affect the existing and future global equity order, and the United Nations must also adopt policies and introduce bills to increase the equity of the relevant fields and the global order.

2. Method

Our method aims to explore the future of asteroid mining, including developing a model for resource allocation, and it is consistent with the concept of "global equity." The analysis of the future impact of asteroid mining programs is studied, and the development of policies to regulate asteroid mining projects and promote global equity.



Figure 1 The mind map of our issue analysis

2.1 Problem Background

The key mathematical notations used in this paper are listed in Table 1.

Table 1. Notations used in this paper

Symbol	Description
AHP	Analytic Hierarchy Process
EWM	Entropy method
GRA	Grey Relational Analysis
GDP	Gross Domestic Product
GiNi	Gini coefficient, measuring income disparity
EPI	Environment performance index
COP	United Nations Framework Convention on Climate Change
P_i	expected emission reduction ratio
EC_i	CO2 reductions per country
RS_i	Resource allocation rate

2.2 Global Equity Measurement

The exploration and use of outer space in the United Nations Outer Space Treaty shall be for all nations' benefit and interest. All nations may conduct outer space activities without discrimination, on an equal footing, and freely. In the definition of global equity, we focus on absolute equity, that is, if a country has more population, resources, etc. More resources and minerals are allocated under the same situation of planetary resource enjoyment. Meanwhile, countries in need of development assistance are allocated subsidies to protect the interests of all countries and achieve fairness.

It is presented a general objective based on the nature and requirements of the problem. The objective is decomposed into several levels layer by layer to build a hierarchical model.

2.2.1. AHP Model

For the model to fully consider the global equity of resource allocation, we selected 14 indicators such as territorial area, population size, total GDP, energy consumption, and Gini coefficient as the measurement factors of equitable distribution. Since there are too many indices, it is challenging to assign weights to indicators of different dimensions. We categorize the indicators into economic, political, environmental, social, and resource factors at the first level. 14 indicators into 2 levels of indicators are used to establish a hierarchical model for evaluating global equity.

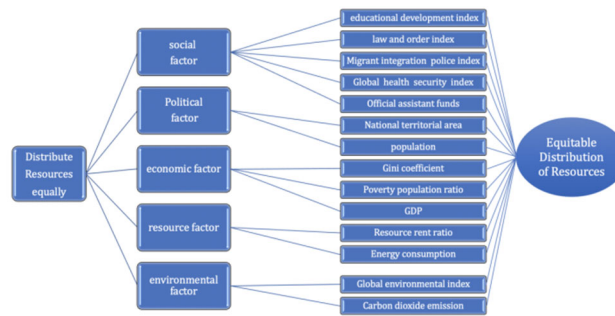


Figure 2 The hierarchical structure model

Let there be a certain layer of n factors $x = \{X_1, \dots, X_n\}$ to compare the degree of their influence on a criterion (or goal) of the previous layer and determine the layer's weight relative to a criterion. The above comparison is between two factors made on a scale. Take 1-9 scale when comparing. It is used a_{ij} indicates the result of the comparison of the first factor i with the first factor j , then:

$$A = (a_{ij})_{n \times n} = \begin{pmatrix} a_{11} & \dots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \dots & a_{nn} \end{pmatrix} \quad (1)$$

Where A is called the pairwise comparison matrix. For a given criterion, the relative weights of each scheme, i.e., the single hierarchical ranking, are calculated and tested for consistency.

Either factor in the matrix (A_{ij}) stands for how more important A_i is than A_j . According to the document, it can be calculated by the formula below:

Normalization of each line of the judging matrix:

$$\bar{A}_{ij} = \frac{A_{ij}}{\sum_{k=1}^n A_{ik}}, i, j = 1, 2, 3 \quad (2)$$

Sum up each judging matrix that has already been normalized in each row:

$$\bar{W}_i = \sum_{j=1}^n \bar{A}_{ij}, j = 1, 2, 3 \quad (3)$$

Where (AW) stands for the i -th component of vector AW .

The last step is consistency check. The formula is $CI = \frac{\lambda_{\max} - n}{n - 1}$, in which RI stands for the index of average random consistency.

The average random consistency index of the first order to ninth order matrix $CR = \frac{CI}{RI} = 0.0176 < 0.1$, Thus, the matrix gets the satisfying consistency.

The relative weights of each scheme are calculated by three methods: average arithmetic method, average geometric method, and eigenvalue method, and the weighted average of the relative weights of each scheme is found.

We consider the order of the significance of the three standards as $C1 > C2 > C3$. Thus, the judging matrix A-C is:

According to the above judgment matrix for consistency ratio test, it is brought into Matlab for calculation. It is calculated that the consistency ratio is 0. Therefore, the consistency of the judgment matrix can be accepted. Next, the test is brought into the program to find out the relative weights of the five first-level indicators of political, economic, resource, social, and environmental factors by the average arithmetic method, average geometric method, and eigenvalue method, respectively. Then, it finds out the weights of the five first-level indicators by the weighted average method (as shown in

Table 2 and Table 3).

In the first layer, we refer to the authoritative Mungus Social Equity Index for ranking the importance of the first-level indicators, which reduces the subjective error to a certain extent. However, it is challenging to use AHP analysis to rank the importance of secondary indicators with low differentiation, which may cause excessive subjective errors. Therefore, we use the entropy method to obtain the weights by analyzing objective data, which is used to reduce the influence of subjectivity on the weights. According to the basic principle of information theory, information measures the degree of order. While entropy measures the degree of disorder of a system. The increase of information means the decrease of entropy. Information is inversely proportional to entropy. The entropy method is an objective weighting method, which can be used to evaluate multiple objects with multiple indicators.

2.2.2. EWM Model

2.2.2.1. Formation of the original data matrix

The existing evaluated object $M=(M_1, M_2, \dots, M_n)$, evaluation index $M=(D_1, D_2, \dots, D_n)$, the value of the evaluated object Mito the index D_j is noted as X_{ij} ($i=1,2, \dots, m; j=1, 2, \dots, n$), then the original data matrix formed is:

$$X = \begin{pmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{pmatrix} \quad (4)$$

Where X_{ij} is the value of the i -th evaluated object under the j -th index.

2.2.2.2. Dimensionless processing of the original matrix

The larger it is, the better the type indicator is.

$$V_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \quad (5)$$

Smaller is a better type indicator.

$$V_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \quad (6)$$

Table 2. Judgment Matrix

A	D_1	D_2	D_3	D_4	D_5
D_1	1	1	2	4	5
D_2	1	1	2	4	5
D_3	1/2	1/2	1	2	5/2
D_4	1/4	1/4	1/2	1	5/4
D_5	1/5	1/5	2/5	4/5	1

Table 3. Consequence Matrix

	political factors	economic factors	Resource factors	social factors	Environmental factor
arithmetical average method	0.3390	0.3390	0.1694	0.0847	0.0676
geometric method	0.3392	0.3392	0.1695	0.0847	0.0678
Feature value method	0.3388	0.3388	0.1696	0.0847	0.0680
method of weighted mean	0.3390	0.3390	0.1695	0.0847	0.0678

2.2.2.3. Calculate the characteristic weight

The characteristic weight of the i -th evaluation object is calculated under the j -th index, and it is noted that the characteristic weight of the i -th evaluation object is under the j -th index is P_{ij} , then.

$$P_{ij} = \frac{V_{ij}}{\sum_{i=1}^m V_{ij}} \quad (7)$$

Because $0 \leq V_{ij} \leq 1$, so $0 \leq P_{ij} \leq 1$.

2.2.2.4. Calculate the entropy value

Calculate the entropy value of the j -th indicator

$$e_j = \frac{-1}{\ln(m) \sum_{i=1}^m P_{ij} \ln P_{ij}} \quad (8)$$

For a certain indicator D_j , the greater the difference of its V_{ij} the smaller the e_j .

The greater the difference in the value of the j -th indicator of each evaluated object. It is indicated that the greater the amount of information reflected by the indicator, the smaller its entropy value.

Moreover, when the entropy value e_j is large, it indicates that the information provided by the indicator is small and can be appropriately considered to be eliminated.

2.2.2.5. Calculate the difference coefficient

Introduce the coefficient of variation d_j :

$$D_j = 1 - e_j \quad (9)$$

The larger D_j is the greater the information provided by the indicator, and the greater the weight should be given to the indicator.

2.2.2.6. Calculate the entropy weight

Determine the entropy weight of each indicator.

$$W_j = \frac{d_j}{\sum_{j=1}^n d_j} \quad (10)$$

2.2.2.5. Calculate the comprehensive evaluation value

Calculate the total evaluation value of each evaluation object separately.

$$V_i = \sum_{j=1}^n W_j P_{ij} \quad (11)$$

2.2.3 model test

By searching the data of secondary indices, we found that some countries have missing data in 2020 for most of the above indices. We take the latest 2020 data, which eliminates the countries with more than 5 or more indices corresponding to missing data. It is used the observations of similar years to replace the retained countries and selected four groups from them: high-income countries, upper-middle-income countries, lower-middle-income countries, and low-income countries. It can get the following sample of 40 countries in all world continents. It can avoid the error of weight calculation due to missing data and at the same time enhance the applicability of the weights and not discriminate the model due to the level of economic development and technological development.

In the hierarchical model, the weights of the primary indicators are multiplied with the weights of the secondary indicators under each indicator separately. To find the weight of each secondary indicator in the overall allocation, a global equity model can be finally obtained to allocate the resources that each country should receive equitably. After the model mentioned above, we believe that the equity index is mainly reflected in "political," "economic," "resource demand," "social," "environment," and other aspects. In order to test the reliability of the global equity index, we can compare it with other official data that can reflect the above "equity." This paper chooses each country's expected CO2 emission reduction in the Paris Agreement as the criterion for model evaluation.

Firstly, we bring the data of 40 countries in the entropy method data sample into the global equity model, which is obtained from the first question to obtain the resource allocation of each country under the equity model RS_i .

Furthermore, the expected emission reduction ratio P_i of the same 40 countries in the Paris

Agreement and the value of carbon dioxide emissions C_i of each country are selected and multiplied to obtain the expected carbon dioxide emission reduction EC_i of each country as the horizontal coordinate X.

Calculate the resource allocation ratio RS_i from the equity index of each country in the equity model as the vertical coordinate Y.

The correlation coefficient of linear regression $R^2=0.9645$ is obtained by linearly fitting the two data to obtain the x-y scatter plot, which indicates that the factors and weights of the equity index are reasonably set.

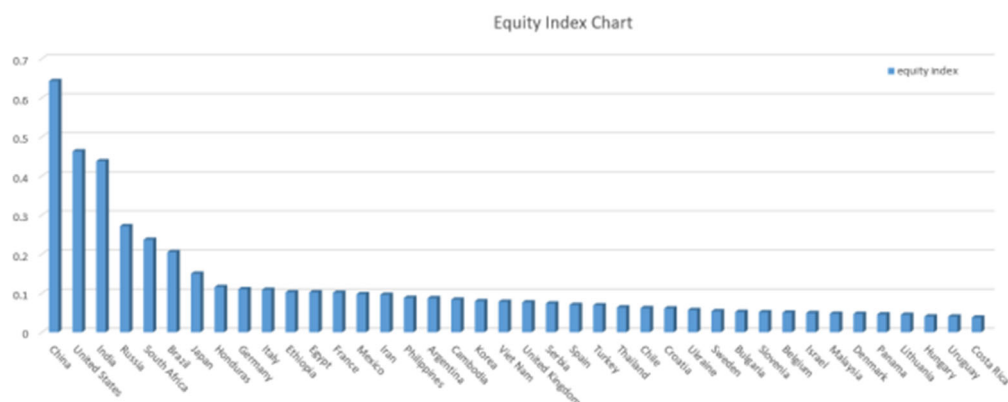


Figure 3 Equity Index Chart

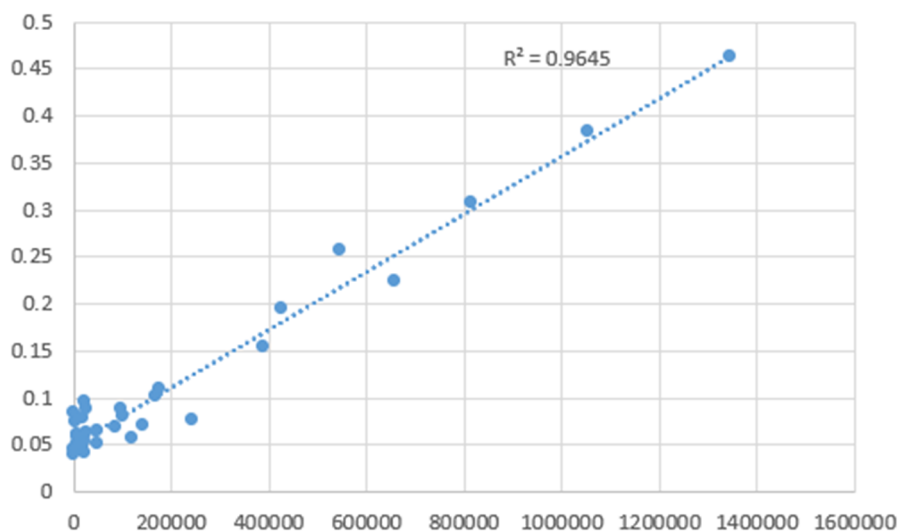


Figure 4 Correlation test results

For image data point distribution problem, most countries are more concentrated in carbon emissions, while the strength gap between countries is large. Some countries' CO2 emissions are much higher than the median data, so most image data points are concentrated near 0, and a small number of data points are scattered above and below the trend line.

2.3 A multidimensional index international equity analysis model

The gray correlation model (GRA), an essential gray system theory model, helps determine each indicator's weights. This paper determines the model's reference and comparison series based on the evaluation matrix. Dimensionless processes the data and finally calculates the weights and resource score values based on the mean value of the correlation coefficients of each indicator and the reference series. The main steps of the gray correlation degree analysis method are shown as follows.

Step 1: Determine the reference sequence and comparison sequence of the reference model.

Step 2: In this paper, the mean value method is used for dimensionless index data processing. X_i^j is the data after dimensionless processing, $\bar{X}_i^j$ is the mean of the numbers, where $i=1,2, \dots, m$.

Step 3: The correlation coefficients of the corresponding factors between the comparison sequence and the reference sequence are calculated.

$$\xi(x_0(k), x_i(k)) = \frac{\min_k \min_i |x_0(k) - x_i(k)| + \rho \max_k \max_i |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max_k \max_i |x_0(k) - x_i(k)|} \quad (12)$$

In formula (12), $i=1,2, \dots, m$, $k=1,2, \dots, N$. ρ is the resolution ratio, which reflects the difference between the correlation coefficients with a value of 0.5.

Step 4: The correlation coefficients of the corresponding factors between the comparison sequence and the reference sequence are calculated.

$$r(X_0, X_i) = \frac{1}{N} \sum_{k=1}^N \xi(x_0(k), x_i(k)), i = 1, 2, \dots, m \quad (13)$$

$$r(X_0, X_i) = \sum_{k=1}^N \omega_j \xi(x_0(k), x_i(k)), i = 1, 2, \dots, m$$

Step 5: The weights of influencing factors were calculated according to relevance.

$$W_i = r(X_0, X_i) / \sum_{i=1}^M r(X_0, X_i), i = 1, 2, \dots, m \quad (14)$$

Step 6: The overall score is calculated according to the weights.

$$Z_i = w_1 x_i(1) + w_2 x_i(2) + \dots + w_n x_i(m) \quad (15)$$

Because there are too many second-level indicators in the hierarchical structure model, it may affect the definition of the weight calculation of the upper indicators from the input-output perspective due to the number of indicators. Therefore, in order to ensure the stability and correctness of the results, five first-level indicators of the hierarchical model, namely, economic factors, political factors, environmental factors, resource factors, and social factors, $(X_1, X_2, X_3, X_4, X_5)$ are

Table 4. The proportion of each country's allocation to asteroid resources

Japan	0.05	Denmark	0.01	Bulgaria	0.01	Chile	0.01
Korea	0.03	Spain	0.01	Hungary	0.01	Uruguay	0.01
China	0.14	France	0.02	Serbia	0.01	Argentina	0.01
Malaysia	0.02	United Kingdom	0.02	Turkey	0.03	Brazil	0.04
Thailand	0.01	Italy	0.01	Ukraine	0.02	Costa Rica	0.01
Philippines	0.01	Slovenia	0.01	India	0.07	Mexico	0.02
Vietnam	0.03	Sweden	0.01	United States	0.12	Panama	0.01
Cambodia	0.01	Croatia	0.01	Israel	0.01	Honduras	0.01
Belgium	0.01	Lithuania	0.01	Iran	0.03	South Africa	0.02
Germany	0.03	Russia	0.06	Egypt	0.02	Ethiopia	0.03

Table 5. Proportion of planetary resources allocated by countries in 2020 θ

Japan	0.03	Denmark	0.01	Bulgaria	0.01	Chile	0.01
Korea	0.01	Spain	0.01	Hungary	0.01	Uruguay	0.01
China	0.14	France	0.02	serbia	0.01	Argentina	0.01
Malaysia	0.02	England	0.02	turkey	0.03	Brazil	0.04
Thailand	0.01	Italy	0.01	Ukraine	0.02	Costa Rica	0.01
Philippines	0.01	Slovenia	0.00	India	0.09	Mexico	0.03
Vietnam	0.04	Sweden	0.01	United States	0.13	Panama	0.01
Cambodia	0.01	Croatia	0.00	Israel	0.01	Honduras	0.01
Belgium	0.01	Lithuania	0.00	Iran	0.04	South Africa	0.02
Germany	0.02	Russia	0.08	Egypt	0.02	Ethiopia	0.04

selected for the selection of gray correlation indicators. Also, from the input-output point of view, since the model assumptions section has been framed that the mining subject is a national government or international organization, the factors selected to influence the contribution of different countries

are mining difficulties, mining cost, and mining revenue. Since there is no practical application and actual data for asteroid mining, it has been assumed in the previous section that the national patented technology water. (X_7) reflects the contribution to the mining difficulty. The national-related aerospace input X_8 reflects the contribution to the mining cost. Since the price paid for mineral resources on asteroids can not be measured and estimated, the price of gasoline, a primary energy source commonly used on Earth today (X_8), reflects the mining benefits.

3. Experimental Results

The optimal values of X_6 , X_7 , X_8 are 13.31, 3.16, and 1.48, respectively. The optimal values are selected as the reference series of the model and combined with the first question to obtain the reference series as.

$$X_0(k) = (11.06, 9.17, 11.06, 5.20, 7.056, 13.31, 3.16, 1.48)$$

Bringing into the model, the average of the correlation coefficients of each indicator and the reference series in each country are found. The weights of the eight indicators in the model of equitable resource allocation are calculated.

An allocation evaluation model with multidimensional indicators recalculated the proportion of each country's allocation to asteroid resources, as shown in Table 4.

To verify that the multidimensional allocation evaluation model incorporating the contribution value indicator in this session is more reasonable than the global equity model obtained in the previous session, the global equity model before the optimization is used to calculate the allocation ratio of each country to asteroid resources, and the results are shown in the following Table 5.

After considering the difficulty, cost, and benefit factors, the countries with the highest allocation ratio under the optimized index system are still China and the United States. The allocation ratio of countries with large populations, such as India, decreases significantly. The allocation ratio of countries with high resource prices, such as the United States, also decreases slightly, including 0.07 for India, 0.12 for the United States, and 0.03 for Ethiopia. In contrast, the allocation ratio of countries with strong technology, such as Germany and Japan, increases significantly to 0.03 and 0.05, respectively. This distribution ensures that the lagging countries have a fair share of resource allocation and provides incentives for the work of the countries that are the main bearers of planetary resource development. Compared with the model in the first question, it is more reasonable.

Compared with the unidimensional global equity model, the multidimensional global equity model leads to an increase in the mining allocation proportion of some countries. A decrease in the allocation proportion of other countries because it considers the contribution and benefit of each country in the planetary mining process. Although this has a large negative effect on global equity in the pure sense, and the absolute global equity seems to be severely compromised, global equity in the relative sense goes up. More mining countries are "rewarded" with the additional allocation shares they deserve. The countries are concerned that profit more from it take a certain allocation share "tax" to preserve equity.

4. Conclusion

EWM and AHP determine the weight of indicators in the Multidimensional index analysis model, and we can avoid errors caused by a single method. Based on the high correlation between the consequence of our model and Emission reductions mandated by the Paris Agreement, we believe the weight of each indicator is reasonable and reliable. Meanwhile, the multidimensional weights' grey correlation analysis method can ensure high reliability through sensitivity analysis. Gray correlation analysis is derived from multidimensional indicator data for 40 countries, and 40 countries cover four different levels of development, so the resulting models have wide applicability and

applicability.

Authors' contributions

The title "AUTHORS' CONTRIBUTIONS" should be in all caps.

Acknowledgments

The title "ACKNOWLEDGMENTS" should be in all caps and should be placed above the references. The references should be consistent within the article and follow the same style. List all the references with full details.

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