ISSN: 1813-4890

When an Asteroid "Takes up Residence" on Earth

Xuanjiao Li, Jizhe Zhao, and Qiuyu Hang

School of Science and Technology Liaoning University, Liaoning 110000, China

Abstract

The current countdown of resources on Earth is underway, and in order to solve the energy crisis, we put our eyes on asteroids in outer space, but the issue of exploitation of asteroids will affect global equity, which is analyzed and discussed in this paper. First, this paper establishes a global equity evaluation model. The weights of the global equity indicator system are determined using the entropy weighting method, which excludes the adverse effects brought by subjective factors. Among them, four primary indicators are used in the paper, and four secondary indicators are established under them respectively for a better description of global equity. The weighting results were then calculated by MATLAB. Then, the global equity was further assessed using TOPSIS method and solved for, and the results obtained for different years were plotted (Figure 2), it can be seen that the global equity gradually deepens with time and asteroid mining will have the required conditions. The next step, From the analysis, asteroid mining in the future will work with intelligent robots and form a complete asteroid mining system. From the sensitivity analysis it is concluded that asteroid mining will deepen global equity from benefits and environment. In addition, we have the ability and the opportunity to leverage relevant technologies, techniques and methodologies with our proven space technology, advanced resource extraction technology, and good development opportunities. However, in the absence of relevant government legislation and lack of space practice, we are confident that in about 10 years, asteroid mining will benefit humanity. Figure 5 shows our plan for the future of asteroid mining. Further, In this paper, four positive and two negative indicators were selected to analyze the impact of asteroid mining on global equity using a control variables approach. Sensitivity analysis is then applied to predict that the results are more sensitive to efficiency and environmental indicators and less sensitive to health and education. Finally, the results are analyzed in the paper, and attention should be paid to the occurrence of environmental pollution and inequitable benefits when mining asteroids. The comparative graphs show that these policies deepen global equity and ensure that asteroid mining can benefit all of humanity.

Keywords

TOPSIS; Entropy Weight Method; Asteroid Mining; Global Equity.

1. Introduction

1.1. Problem Background

From the last century, mankind first launched the satellite into the sky, opening up the human space age, after which mankind tried to send animals overhead, to finally mankind into space, which sounds too incredible, and this is exactly what we experienced, then we explored the moon, Mars, and female astronauts into space, more and more people want to go to become an astronaut, and maybe even our childhood dream is Become an astronaut, with the success of the human landing on the moon, bringing us unlimited enjoyment. This is a small step for me personally, but a big step for humanity!" -- Amster. It was a miracle in the history of science, and they brought back soil samples from the moon, after which man explored more planets and built space stations in space, so we all space had a bolder blind idea and will act, that is, to get resources from space for our use.

1.2. Restatement of the Problem

Considering the background information and restricted conditions identified in the problem statement, we need to solve the following problems:

Problem 1 To measure global equity, i.e., to define the development of global equity, we need to develop a model, such as tools, indicators, etc., based on a careful historical and regional analysis of the conditions that exist and their context, and use this model as our standard for measuring global equity.

Problem 2 What are the implications for global equity when conditions change at the time of definition? Requires the use of an analytical approach to explore how global equity is affected by changes in the asteroid mining industry.

Problem 3 What are the global equity and benefit implications of our approach to asteroid mining?

Problem 4 With the UN considering updating the outer space treaties, what policies can we adopt to promote an equitable approach to development?

1.3. Our Work

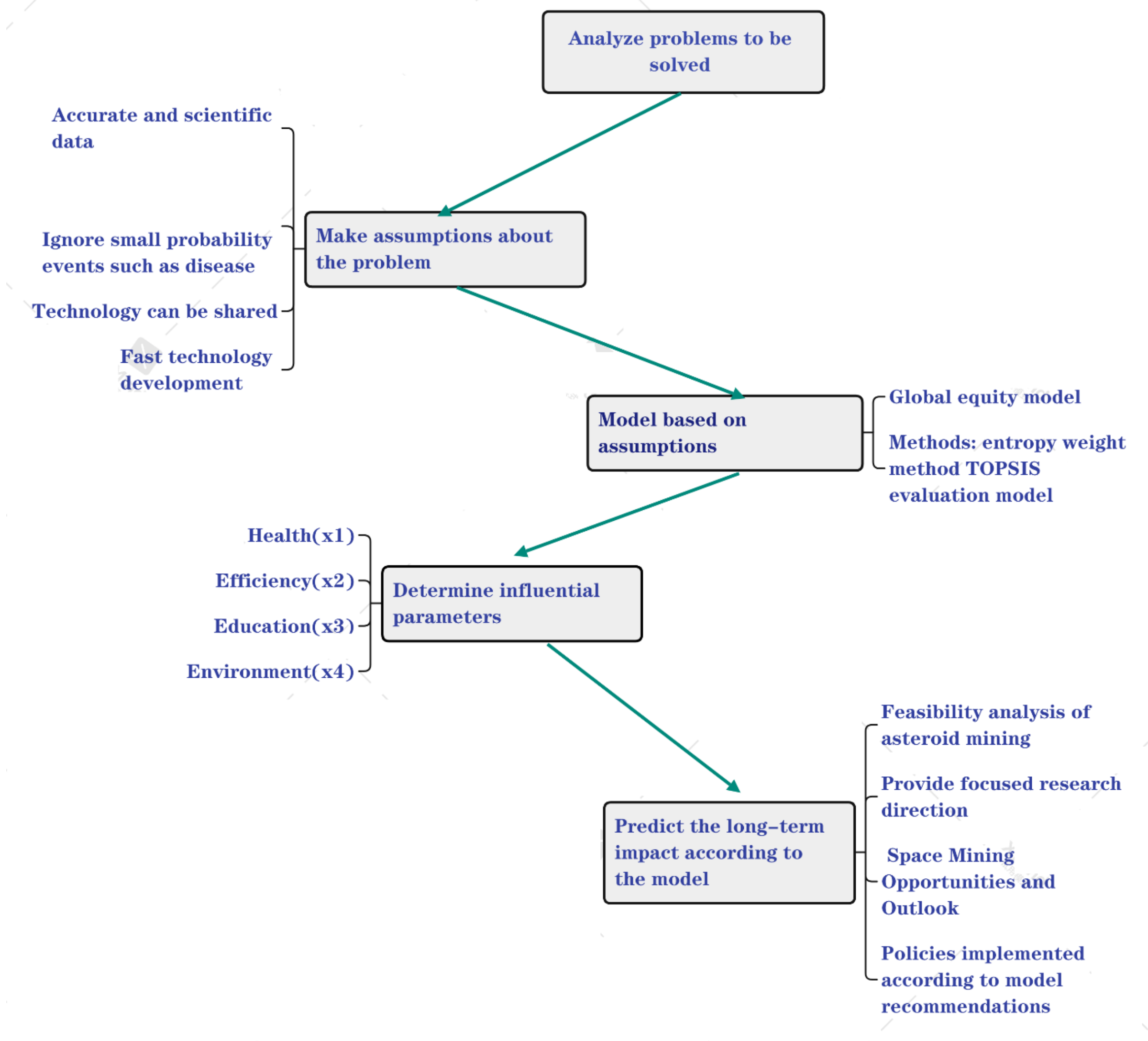

Figure 1. Mind map

First, we established a global equity system with health, efficiency, education and environment as the primary indicator environment, and four secondary indicators were selected under it respectively. The entropy weight method was applied to determine the indicator weights, and the model was solved through MATLAB programming.

Next, we adopted the TOPSIS method to construct the global equity assessment model and derived the fit under each indicator.

Secondly, we analyzed the feasibility of mining asteroids. And the exploration direction of mining was determined. Then a possible future vision of asteroid mining is proposed.

Next, we carefully planned asteroid mining and drew a flow chart to analyze each step, and elaborated on the world aviation history with reference to time, and predicted the future asteroid mining globally.

Then, in studying the impact on asteroid mining, we used the control variables method. The indicators are the availability of mature space technology, the availability of advanced resource extraction technology, the ability to make good use of relevant technologies and methods, good development opportunities, the availability of relevant governmental legislative support, and the availability of sufficient space practices, respectively, and their explanations.

Finally, we perform a sensitivity analysis of the model we constructed and evaluate the model, including strengths and weaknesses, and further discussion.

The mind map is shown in Figure 1.

2. Assumptions and Justifications

In order to simplify the given problem and modify it to be more fit for simulating real life conditions, we make the following basic assumptions.

Assumption 1: We assume that the data found is accurate and scientific.

Explanation: We used authoritative international websites when finding data, so we can assume that the data is credible. For some indicators where data are missing, we have the flexibility to use other available data, reducing the subjective element and providing greater data accuracy. This is because aspects of global equity are not reflected by just one indicator, and the data can be corrected by certain methods. This may be the result of a combination of many factors.

Assumption 2: We assume a globally equitable health scale that does not consider the occurrence of small probability events for diseases such as those below level 3 disability.

Explanation: Diseases are not inevitable in affecting health, but today, medical environments and conditions are becoming more and more complete, so these diseases can be identified as small probability events affecting a globally equitable level of health, so the disease factor for workable people can be ignored and a perfect health class can be established.

Assumption 3: We assume that the UN supports asteroid mining and that the technology will be shared.

Explanation: The United Nations should introduce international public law to support asteroid mining, which will facilitate the mining to be done in an orderly manner. This is closer to our theme that technology sharing is better for world equity, plays a positive role and strengthens the international status of the UN, which is another step for human welfare.

Assumption 4: We assume that within a few years, humans will have matured and mastered asteroid mining technology and transportation.

Explanation: Through the current economic and technological prosperity of the world, asteroid mining technology will also be perfected, and having a proven mining system will ensure safety issues, so we do not have to consider the safety of the asteroid mining process, and the technology can be perfected in the last few years, then research funding we can ignore. In addition, we are also interested in the emergence of an asteroid mining industry as a prerequisite, which is more conducive to the implementation of our plan.

Assumption 5: We assume that asteroid mining will not return to Earth with polluting minerals and will not exacerbate other harmful products of the Earth's environment such as the greenhouse effect.

Explanation: The earth's greenhouse effect is serious, and if the minerals that produce pollution are carried, it will aggravate the pollution and endanger the interests of human beings, so the safety and environmental protection of the mineral products should be guaranteed before mining.

3. Notations

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

Table 1. Notations used in this paper

Symbol	Description
X_{aj}	Value of the jth indicator of the ath evaluation sample
e_j	Indicator information entropy
d_j	Coefficient of variance
w_j	Entropy weighting of indicators
z_j^+	Positive ideal point of the sample object
z_j^-	Negative ideal point of the sample object
C_a	Proximity

4. Definition of Fairness

In a society or organization, the distribution of one or more rights is fair or socially equitable to a certain extent if the satisfaction rate of the public (all members of the distribution) is higher than the dissatisfaction rate; if the satisfaction rate of the public is equal to or lower than the dissatisfaction rate, the distribution is not fair or socially equitable. Accordingly, the higher the satisfaction rate, the more equitable [1] the lower the satisfaction rate, the less equitable the distribution.

5. Entropy Weight Method

5.1. Data Description

For the design of an evaluation system, collecting sufficient data is one of the most essential steps. Our data are taken from authoritative international websites. Therefore, to a certain extent, the authenticity of the data can be guaranteed. Most of our data are mainly selected from developing countries like China. To ensure the scientific validity of our data as much as possible, we also collect global per person data.

5.2. The Establishment of Entropy Weight Method

The entropy weight method [2] is compared with subjective methods such as hierarchical analysis.

Assignment method is more objective and better able to interpret the results compared to hierarchical analysis, which utilizes weighting using the variability between information, but using this method requires a partial sample size, determine the weights from the sample, and then analyze them according to the determined weights.

The main steps of the analysis [3] are as follows:

1) Positive convergence and standardization of the initial data. After the consistency treatment of negative indicators using the subtractive consistency method, the processed indicators are standardized according to the following equation.

$$X_{aj} = \frac{x_{aj}}{\sqrt{\sum_{a=1}^{m} x_{aj}^2}} \tag{1}$$

2) Next, the characteristic weight of the jth indicator of the ath evaluation sample is calculated. The calculation formula is as follows.

$$P_{aj} = \frac{X_{aj}}{\sum_{a=1}^{m} X_{aj}} \tag{2}$$

3) The calculation of the information entropy of each index is being performed. The calculation formula is as follows.

$$e_j = \frac{1}{\ln m} \sum_{a=1}^{m} P_{aj} \ln P_{aj} \tag{3}$$

When the information of a system is zero, its entropy value e_j = 1. A larger e_j indicates that the indicator provides less information, i.e., the indicator has little impact on the evaluation, and can be considered for elimination.

4) Finally, the coefficient of variation and indicator weights were calculated. The calculation formula is as follows.

$$d_j = 1 - e_j \tag{4}$$

$$w_j = \frac{e_j}{\sum_{j=1}^{n} e_j} \tag{5}$$

5.3. The Solution of Entropy Weight Method

Indicator weights. We constructed a global equity evaluation indicator system and calculated objective weights using the EWM method, and the results are shown in Table 2. From the results, we can easily see that, among the four first-level indicators we selected, environment is the factor with the least impact on global equity, and its impact on global equity is almost negligible compared with several other factors. The biggest impact on global equity is the indicator of health, and the indicators of efficiency and education have little difference in their impact on the global equity system, both above 30%. Therefore, for us to conduct asteroid mining, if we can improve the two indicators of efficiency and health to a greater extent, it will be a good contribution to global equity, which will help to reduce the disparity of treatment and increase global equity.

ISSN: 1813-4890

Table 2. Calculation results of indicator weights

First grade indexes	Weight	Second grade indexes	Weight
Health(x_1)	0.5058	Average life expectancy(x_{11})	0.0006
		Government Health Spending(x_{12})	0.2717
		Food availability per capita(x_{13})	0.0024
		Per capita medical expenditure(x_{14})	0.2311
Efficiency(x_2)	0.2046	Disposable income per capita(x_{21})	0.1503
		Ratio of men to women(x_{22})	0
		Taxation of personal and corporate income(x_{23})	0.0095
		Trade and cost of living(x_{24})	0.0448
Education(x_3)	0.2356	Average number of years of schooling(x_{31})	0.0682
		Gender ratio of average school age(x_{32})	0.0011
		Education expenses(x_{33})	0.1559
		Proportion of high school to higher education(x_{34})	0.0104
Environment(x_4)	0.0540	CO2 emissions per capita(x_{41})	0.0037
		Nitrogen fertilizer use(x_{42})	0.0111
		Share of food emissions(x_{43})	0.0203
		Material footprint per capita(x_{44})	0.0189

6. Global Equity Evaluation Model

6.1. The Establishment of Global Equity Evaluation Model

TOPSIS method [4], also known as the superior-disadvantageous solution distance method, is an effective multi-indicator evaluation method. Its advantages avoid the subjectivity of the data, do not require an objective function, and do not have to pass the test.TOPSIS is a decision method for multi-objective decision analysis in a finite solution, which finds the optimal and the second best solution in a finite solution from the normalized original data matrix, determines the distance between the sample object and the positive (negative) ideal point, and then finds the closeness of the sample object to the ideal point sample object and the closeness of the ideal point [5- 7]. The main steps are as follows.

1) First, we build the initial computational matrix $\mathbf{X} = (x_{aj})_{\mathrm{m}\times\mathrm{n}}$.

2) Second, we process the initial computational matrix so that it is normalized to $\mathbf{B} = (b_{aj})_{\mathrm{m}\times\mathrm{n}}$.

3) Third, we constructed the weighting matrix. Using the algebraic method to determine the combined weight vector $\mathbf{W} = (w_{co1}, w_{co2}, \cdots, w_{co4})^T$, the weighted normalized decision matrix $\mathbf{Z} = (z_{aj})_{\mathrm{m}\times\mathrm{n}}$, where $z_{aj} = w_{coi} \times b_{aj}$, is constructed by $\mathbf{Z} = \mathbf{B} \times \mathbf{W}$.

4) Finally, the distance $D_a^+(D_a^-)$ and the closeness C_a of the sample object to the positive (negative) ideal point are calculated. $C_a \in [0, 1]$, the closer the value is to 1, the closer the sample is to the positive ideal point, the better the calculation result is; conversely, the worse it is. Its calculation formula is as follows.

$$D_a^+ = \sqrt{\sum_{j=1}^{n}\left(z_j^+ - z_{aj}\right)^2} \tag{6}$$

$$D_a^- = \sqrt{\sum_{j=1}^{n}\left(z_j^- - z_{aj}\right)^2} \tag{7}$$

$$C_a = \frac{D_a^-}{D_a^+ + D_a^-} \quad (8)$$

6.2. The Solution of Global Equity Evaluation Model

The global fairness proximity C_a is calculated using Eqs. (6) to (8), and the results are shown in Table 3.

Table 3. Calculation results of global equity proximity $\boldsymbol{C_a}$

Year	Health	Efficiency	Education	Environment	Comprehensive
2011	0	0.0014	0.0091	0	0.0047
2012	0.014	0.0219	0.0575	0.0244	0.0336
2013	0.0306	0.0449	0.0669	0.0576	0.0453
2014	0.0514	0.0666	0.0768	0.0904	0.0611
2015	0.0815	0.0716	0.0907	0.1004	0.0817
2016	0.1081	0.0934	0.1034	0.1425	0.1035
2017	0.1332	0.1399	0.1214	0.1473	0.1291
2018	0.1625	0.1616	0.1402	0.1381	0.154
2019	0.1839	0.1831	0.163	0.1387	0.1736
2020	0.2348	0.2158	0.171	0.1606	0.2133

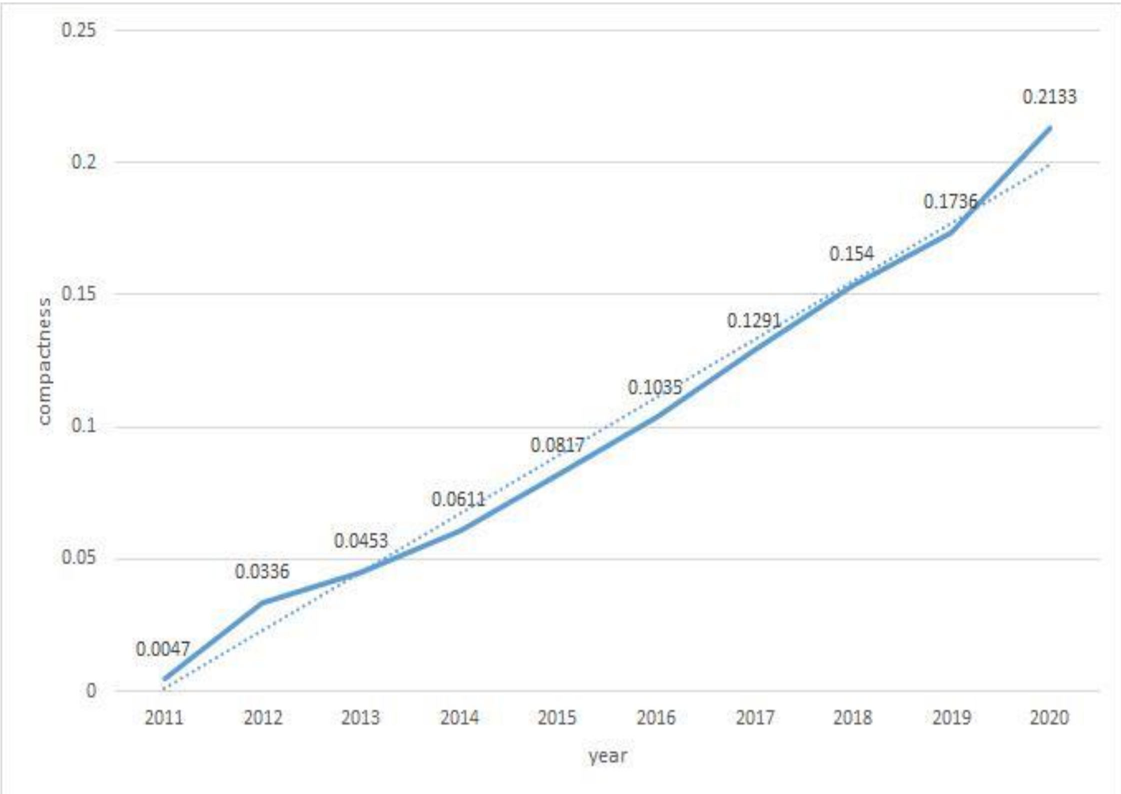

Figure 2. Comprehensive evaluation results

Total allocation [8] is the core of total control, which integrates regional social conditions, economic development, environmental status, and human health degree, etc. Sustainable development, quantitative management, and economic viewpoints are introduced into global fairness judgment, and total indicators are reasonably allocated to each allocation unit to deepen the degree of full fairness. From Figure 2, we can see that with the development of human destiny community, the degree of global equity deepens, and the equity gradually strengthens with the change of time, showing a linear development, and at the later stage the degree of equity is more deviated from the curve upward, and the equity index becomes higher and higher, and with the deepening of the degree, the vision of mining in asteroids will be easily realized.

7. Asteroid Mining

7.1. Asteroid Mining Feasibility Analysis

Asteroids [9] in the solar system are mainly divided into near-Earth asteroids and main belt asteroids according to their orbital positions. It is observed that the main ring belt of asteroids has up to 750,000 asteroids, among which more than 30 asteroids have a diameter of more than 200 km. There are more than 2300 near-Earth asteroids, among which about 1000 have a diameter of more than 1 km. According to related research results, about 1500 near-Earth asteroids can be our main target stars for space mining. According to the spectral characteristics, asteroids can be classified into C-class (carbonaceous) asteroids, S-class (siliceous) asteroids, M-class (metallic) asteroids and so on. Among them, C and M class asteroids are considered to contain huge mineral resources and economic value, which can be used by human. Carbon asteroids are rich in carbon, hydrogen, oxygen, nitrogen and other elements, which can provide fuel for deep space exploration and can be used as a supply station for space exploration. As human deep space exploration activities continue to increase and deep space exploration capabilities continue to strengthen, humans are gaining the ability to go to asteroids for mining. Currently, NASA and Japan have launched probes for unmanned close exploration of asteroids, and the U.S. is also preparing to conduct close research on asteroids in the asteroid belt in close orbit in 2025. It is believed that with the development of science and technology, especially the development of space technology and modern mining technology and the increasing ability of human deep space exploration, the development and utilization of rich resources on asteroids, especially near-Earth asteroids, will no longer be a fantasy (Figure 3).

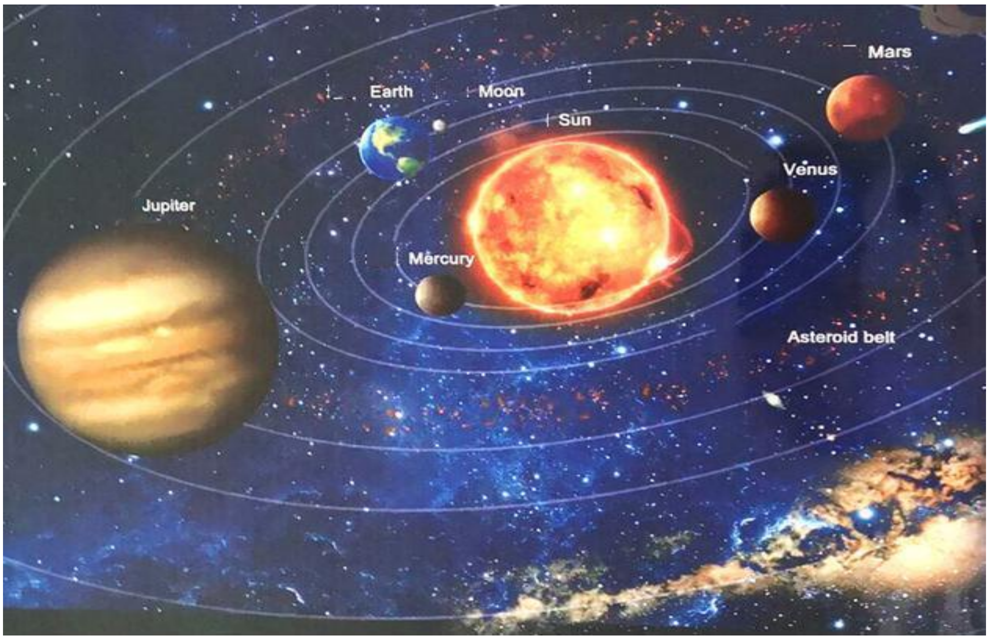

Figure 3. Schematic diagram of target orbit and position relative to earth for explanation of space resources in solar system

7.2. Focused Research Direction

Although the idea of mining space resources was proposed by Konstantin Tsiolkovsky as early as 1903 [10], it has not been practiced. In recent years, the idea of space mining has received renewed attention due to the decrease in Earth's resources and the rapid development of space and aviation technologies. However, since the research on space mining has just started, scientists have combined their knowledge of space information science, mining science and other aspects of space mining research progress accumulated over the years to propose the main research directions and routes to be focused on (Figure 4).

1) Space Resource Exploration.

2) Manufacturing and design of intelligent robotic platform for space mining.

3) Space Resource Exploration and Extraction.

4) In-situ utilization of space mining resources and space safety.

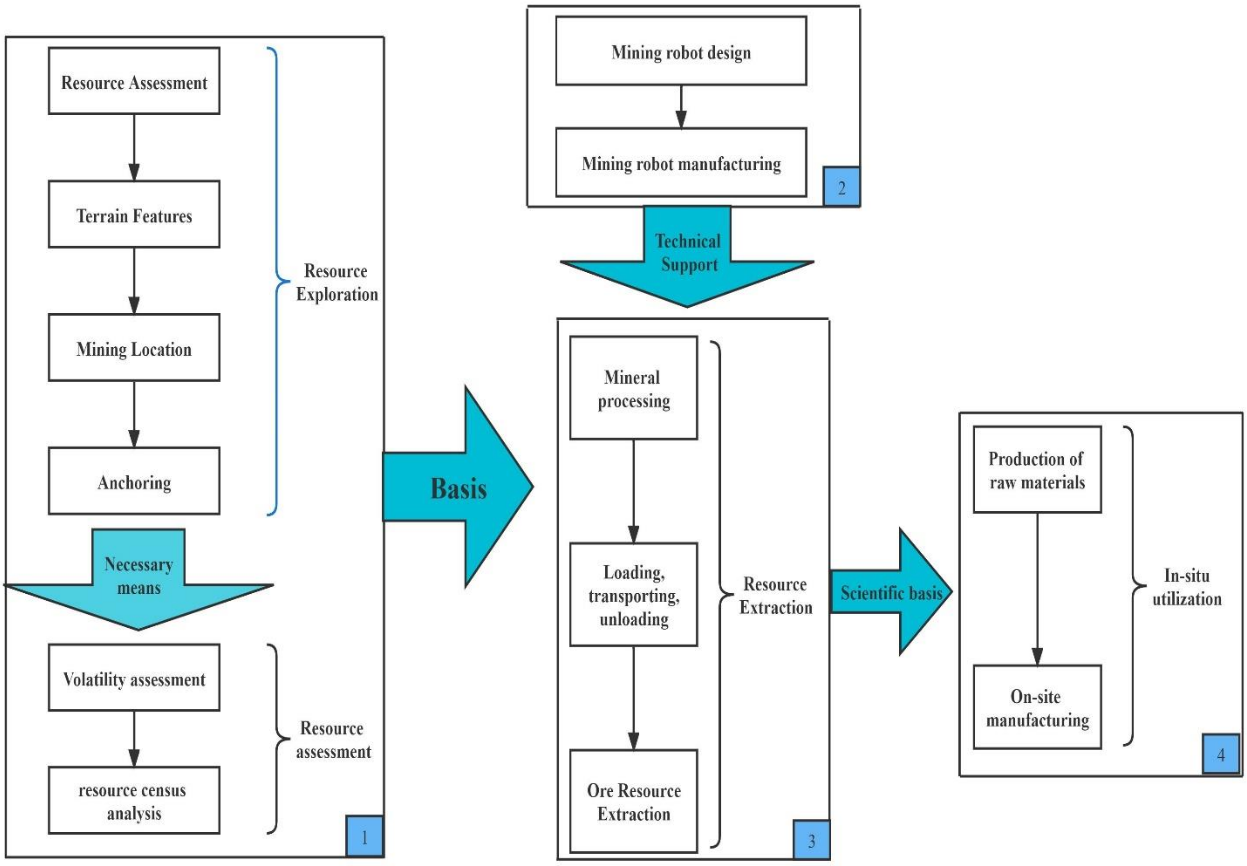

Figure 4. Space mining research roadmap

8. Space Mining Opportunities and Outlook

In recent years, the world has made rapid progress in aerospace technology, and the U.S. space budget for 2020 alone is $57.8 billion a year. And so far, we have achieved a soft landing on the back of the moon to explore the spacecraft - Chang'e 4, its main task is to land on the surface of the moon, continue to deeper and more comprehensive scientific exploration of the moon's geology, resources and other aspects of information, improve the lunar archives. On February 9, 2021, the "Hope" orbiter of the United Arab Emirates arrived at Mars; on February 10, 2021, the Chinese "Tianwen-1" probe successfully entered Mars orbit, landed on May 14, and deployed on May 22. "The Zhurong rover; NASA's Perseverance rover lands in Jezero Crater on February 18, 2021. NASA's Mars Helicopter Jiji successfully lands on the surface of Mars aboard the Rover Trail in February 2021, and completes its flight on the surface of Mars on April 19. After completing five flights, Jiji transitioned from technology demonstration to extended

ISSN: 1813-4890

operational testing and completed its 17th flight on December 3. Blue Origin's New Shepard vehicle completed its first manned space flight on July 20, 2021, with the participation of the company's founder Jeff Bezos. Blue Origin completes its third manned flight on Dec. 11, 2021. Japanese startup Astroscale has validated its magnetic capture system designed to solve the space debris problem in August. The company's ELSA-d server satellite used the system for the first time to successfully capture a piece of simulated space debris in orbit. This is one of the remarkable achievements that we have witnessed, signifying that the world has a better foundation for aerospace, and that advanced technologies, equipment, and methods for mineral resource extraction and utilization are now available [11-13], laying the foundation for the world's space mining practices.

In general, the technology required for space mining is now available, and there is a very good opportunity for development. With the support and agreement of the United Nations as a guarantee, we firmly believe that in about 10 years' time, asteroid mining will benefit humanity and promote the unity of the world's people. Figure 5 shows our plan for the future of asteroid mining.

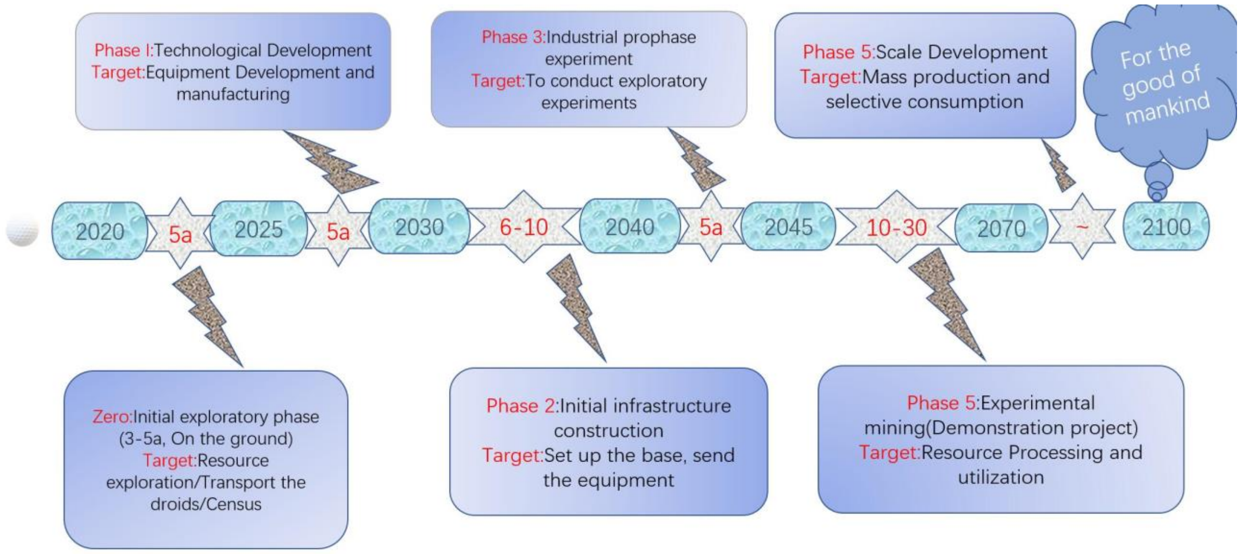

Figure 5. Schedule of space mining development in China

9. Effect of Changes in Prescribed Conditions

Based on the existing world pattern, the future of asteroid mining has both advantages and disadvantages for us. In the face of a rapidly developing world, the consumption of various raw materials, metals, and coal is extremely high. If asteroid mining is possible, it is significant in the long run, and the abundance of asteroid mineral resources can be a good remedy for the energy crisis. Our team uses a control variables approach to analyze the impact of asteroid mining voyages on future global equity. The indicators we now discuss are as follows. Positive indicators: mature space technology, advanced resource extraction technology, ability to make good use of relevant technologies and methods, good development opportunities; negative indicators: relevant government legislation support, lack of space practice. Let's analyze them one by one, but of course, we analyze one of them without considering the other variables, i.e., the other variables are held constant by default. For us at present, mature aerospace technology is the key to our asteroid mining and the first step, just like a person cannot swim and no bridge, the water is still very deep, we need to build a boat to cross the river, we want to go to outer space to mine we need to have mature aerospace technology to support our first step. When we space technology is more developed, we can go to outer space more often, as a good carrier. Of course, if our space technology is not developed, we cannot guarantee the safety of space, and even outer space cannot go, so mining asteroids is an impossible thing. Then analyze the advanced resource mining technology, this is the second step, we reached the asteroid if you cannot mine resources that is also futile, many mineral resources are buried underground, first we need to detect the location of mineral resources to reduce useless work. A more important point is that the environment of the asteroid and we live on Earth is very different, the environment is also harsh, the lack of oxygen, then a strong mining technology is particularly important, if the mining technology is not enough, it will bring us great trouble and may even endanger the lives of mining personnel. Let's talk about the ability to make good use of the relevant technology and methods, we firmly believe that this is also as a key factor in asteroid mining, I'll explain why, I'll start with a simple example of a junction with a large stone that needs to be moved, when we think of using the principle of leverage to solve the problem, so for this variable the purpose is to save our resources and improve efficiency, do not turn a simple problem Because the ability to use technology is not enough to become a difficult problem, I think this is both a waste of time and increase the cost of mining, so if we are not good at using the relevant technology and methods of capacity, we mining costs will increase, that is, to reduce revenue. Good opportunities for development are created for us by the continuous efforts of our predecessors, and we cannot afford to miss this opportunity and seize it for development, if there is no opportunity there will be no vision of mining asteroids. The problem now is that the relevant government legislation does not play a role in promoting the industry, we need appropriate legislation as a support to encourage the development of the industry in the country, with legislation as a guarantee, but we also need the government to carry out the necessary control of the industry, do not let the mining of asteroids into a private monopoly to obtain the means of profiteering, but for the benefit of the people of the world. Without government support, even if the industry develops, it will become a means for a few people to earn profits, which is unfair to the people of the world. Even though we have a detailed plan for asteroid mining, we have not practiced asteroid mining as of now, and we know that any success is paved with practice, as Edison did with the light bulb, so we need to keep practicing it, which is our inevitable choice to success.

10. Policies and Recommendations

Safe and effective measurement methods should be established and the possible problems of asteroid mining should be carefully analyzed to prevent accidents such as Earth disasters.

To protect the Moon, planets, asteroids, and any other celestial body by legalizing and granting ownership of resource extraction.

The industry should develop under strong government intervention and guidance, and not be left to develop freely, or it will upset the balance.

Countries around the world should work together to develop corresponding international laws [14] to prevent disagreement over the ownership of resources.

There needs to be stronger restrictions on private entity development that are not too basic. The scale of private development should be limited and monopolies should be rejected.

The international legal system should explore foreign stars not only in principle, but the law should change with the status quo in space, i.e., it should be developed with more than just the current problem in mind.

11. Sensitivity Analysis

In the previous section, we constructed the entropy weight method to find the global equity weight model, and then constructed the global equity assessment model by the TOPSIS method to derive the fit under each dimension of global equity. We performed sensitivity analysis on the model, as follows.

We changed the secondary indicators individually and analyzed the impact of such changes on the primary indicators. We observe the change in the fit of the primary indicators before and after the change. The faster this change is obtained by changing each secondary indicator individually, the more sensitive the model is. Conversely, the slower the change, the slower the model sensitivity (Figure 6).

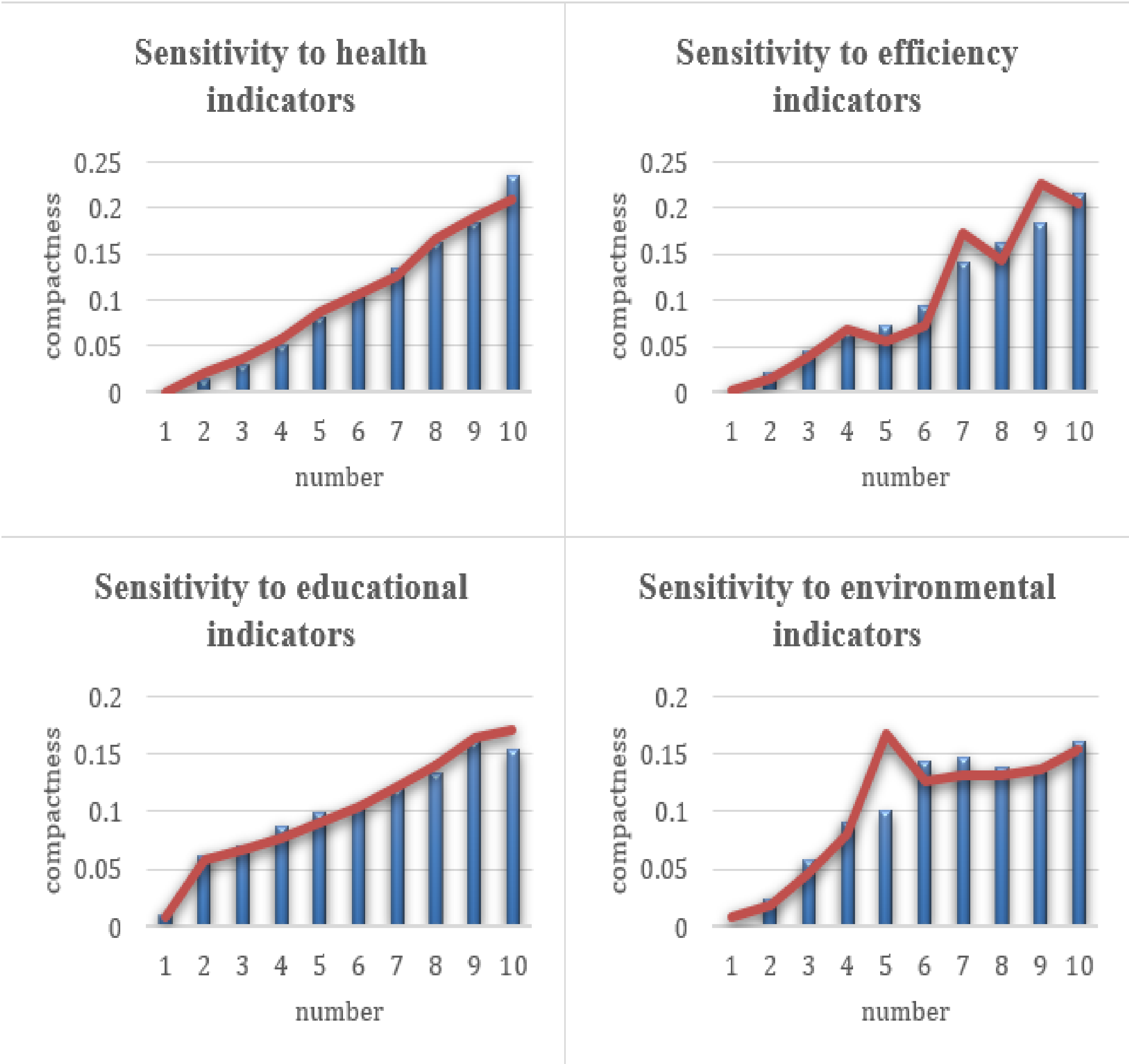

Figure 6. Sensitivity analysis of the model

As can be seen from the above graph, when the secondary indicators under the primary indicators change, there is a more significant effect on the two indicators of efficiency and environment; for the two indicators of health and education there is a non-significant effect. Therefore, the scoring results are more sensitive to the indicators of efficiency and environment, and less sensitive to health and education

12. Conclusion

1) In this paper, we have developed a global equity weighting model to objectively solve for the relative importance of each indicator of global equity. We also built a global equity evaluation model to derive the fit of each dimension.

2) Based on the above two models, we selected the world as a reference object to develop a vision for asteroid mining in the next ten years. At the same time, we give policy recommendations to promote global equity under the assumption that the United Nations is considering an update of the outer space treaties.

References

[1] Wang Yiduo. On the operable definition of the concept of fairness [J]. Journal of Southwest University for Nationalities (Humanities and Social Sciences Edition), 2005(10):198-202.

[2] Du Xuefang, Li Yanbin, Zhang Xiuyu. Research on water resources carrying capacity of Zhengzhou city based on TOPSIS model[J]. People's Yellow River,2022,44(02):84-88.

[3] Zhang Xianqi, Liang Chuan. The application of entropy-based fuzzy element model in the comprehensive evaluation of water quality [J]. The application of entropy-based fuzzy element model in water quality evaluation [J]. Journal of Water Resources, 2005, 36(9): 1057-1061.

[4] Zhong Gangpeng, Xu Wei, Wang Ning, Cao Ting, He Renxin. Evaluation of compensation level of self-funded medical supplemental insurance for employees in city A of Jiangsu province based on TOPSIS method[J]. Health Soft Science,2022,36(02):72-77.

[5] Sun Yan, Yang Kan, Liu Jianlin, et al. Reclaimed water quality evaluation model based on TOPSIS and variable-weight fuzzy water quality evaluation model based on TOPSIS and variable weight fuzzy [J]. People's Yellow River, 2018, 40(8): 57-61.

[6] Wang Jiang, Li Jing, Wei Hongyi, et al. Regional water resources carrying capacity prediction and evaluation based on TOPSIS method: taking Guanzhong region of Shaanxi Province as an example [J]. Soil and Water Conservation Research, 2008, 15(3): 161-163.

[7] Wang Yining, Sun Leqiang, Wang Zhenlong, et al. Comprehensive evaluation of water supply security in northern Anhui area [J]. Water Resources and Hydropower Technology, 2012, 43(1): 30-34.

[8] Sun H. Aerospace academician: China can go to asteroid mining within 10 years if it wants to do it[J]. Computers and Networks,2017,43(20):17.

[9] Zhang Kefei, Li Huaizhan, Wang Yunjia, Deng Kazhong, Li Changgui, Wang Qianxin, Liu Xinhua, Xie Yaoshe, Duan Yabo, Yang Yang. Current status, opportunities and challenges of space mining development[J]. Journal of China University of Mining and Technology,2020,49(06): 1025-1034. DOI: 10.13247/j.cnki.jcumt.001165.

[10] WIKIPEDIA. Konstantin Tsiolkovsky [EB / OL]. (2020 - 01 - 01) [2020 - 01 - 01]. https: //en. wikipedia. org / wikiorg / wiki/ Konstantin Tsiolkovsky.

[11] WANG Guofa, ZHANG Desheng. Innovation practice and development prospect of intelligent fully mechanized technology for coal mining [J]. J .Journal of Journal of China University of Mining & Technology 2018, 47 (3). 459 - 467.

[12] GE Shirong. Chemical mining technology for deep coal resources [J].Journal of China University of Mining &Technology, 2017, 46(4):679-691.

[13] YUAN Liang, ZHANG Tong, ZHAO Yixin, et al. Precise coordinated mining of coal and associated re-sources: A case of environmental coordinated mining of coal and associated rare metal in Ordos basin[J].Journal of China University of Mining & Technology, 2017, 46(3): 449 -459.

[14] Google. Study on the U.S. Outer Space Resources Exploration and Use Act [D]. Shenzhen University, 2018.