Creation of Production Facilities in Near Space (On the Example of Extractive and Manufacturing Industries)

A. Unitsky[1,2],
Dr. of Transport Philosophy

S. Artyushevsky[2]

A. Klimkov[2],
Ph.D. in Economic Sciences

O. Klimkova[3]

[1] Astroengineering Technologies LLC, Minsk, Belarus

[2] Unitsky String Technologies Inc., Minsk, Belarus

[3] Alma-Dent LLC, Minsk, Belarus

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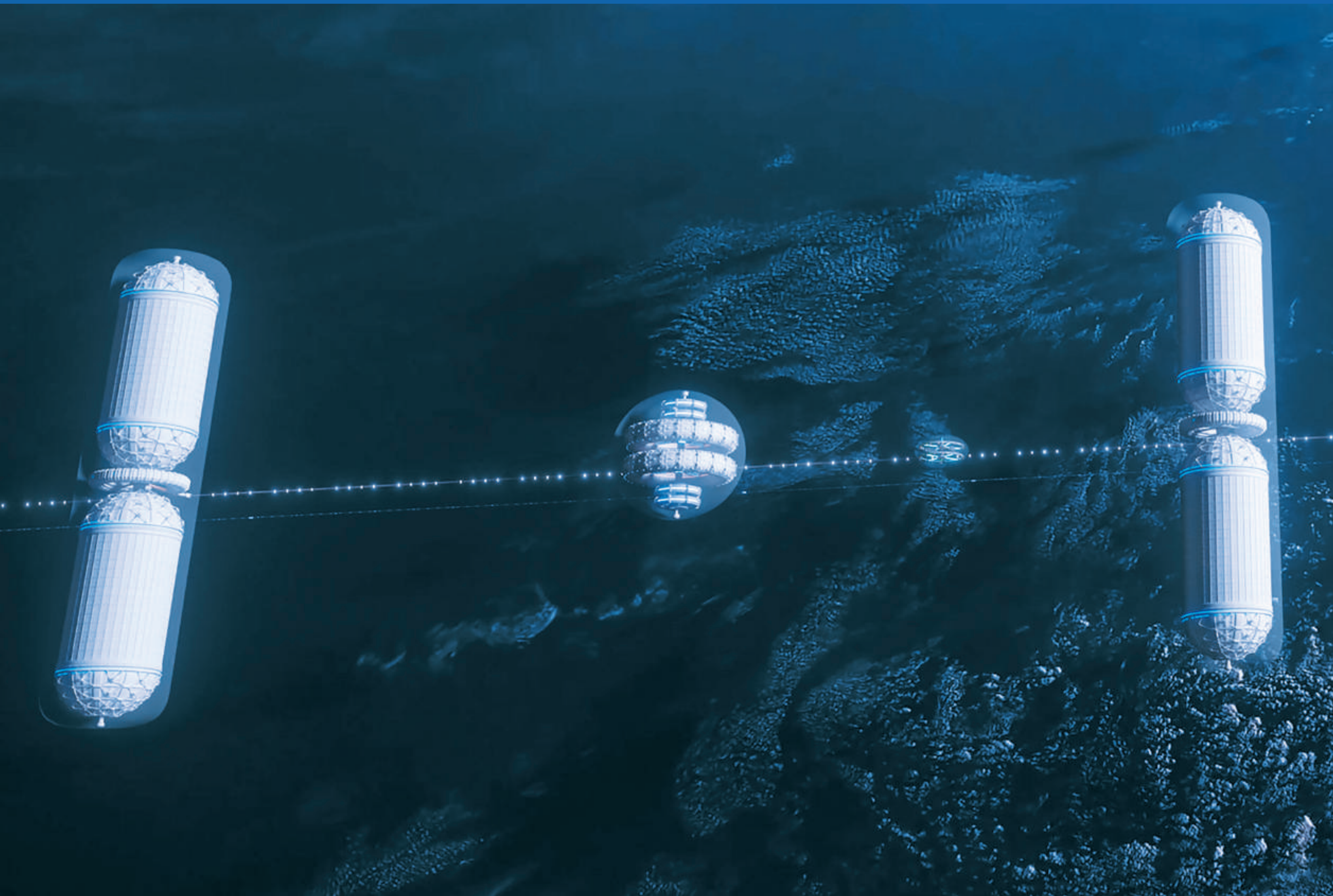

Based on a review of scientific literature, we confirmed the urgent need for space industrialization, creation of full-fledged industries in near-Earth space. In accordance with the methodology developed by the authors, including the use of statistical data and the method of expert evaluation, terrestrial industries (both extractive and manufacturing) were ranked to identify the feasibility of creating the corresponding production facilities in near space. Based on the results obtained in the course of the study, we made conclusions, as well as gave recommendations for their practical use.

Keywords: *criterion, evaluation methodology, expert evaluation, extractive industry, manufacturing industry, near space, practicability index, ranking, space industrialization, statistical data.*

Introduction

You all know that a favorable natural environment is a prerequisite and basis for economic prosperity and the health of humanity. At the same time, unsustainable patterns and global trends of manufacture and consumption, increasing the scale of use of natural resources, driven by population growth, technocratic and consumptive nature of human development, expose it more and more at risk, not coming closer to achieving the goals of sustainable development. Such changes are rapidly worsening the environmental, demographic and several other components of life on Earth, threatening to reduce to zero the progress in all spheres of life that has been made over the past 50 years. In order to eliminate the negative consequences and restore a healthy existence of all mankind, it is crucial to implement effective measures and strengthen international cooperation [1] to reduce greenhouse gas emissions, to switch to green transport and to create industries in outer space. One of the most global and obvious actions is the industrial development of space, the rationale for which is given in numerous writings of scientists, starting with K. Tsiolkovsky [2, 3].

It was back in 1911–1912 when K. Tsiolkovsky emphasized the high cost and low productivity of rocket technology [3], requiring significant fuel costs to carry cargo from Earth to orbit with the extremely grave ecological hazard of such geocosmic transportations.

The concept of non-rocket complex solution of space industrialization and scientific and engineering substantiation of such a project was proposed by engineer A. Unitsky [4, 5] through the General Planetary Vehicle (GPV) and Unitsky String Technologies (uST).

Despite the relevance and inevitability of near space industrialization, numerous scientific papers have so far revealed virtually no studies addressed to one important problem: how exactly (including with respect to the methodological approach) to select sectors of industry for their future functioning in near space.

In [6], the relevance of the creation of production facilities (using the example of specific sectors and enterprises) in Earth orbit is researched, taking into account a number of criteria, and a methodological approach to assessing the practicability of moving production facilities to near space is developed (the theoretical part is presented, without practical evaluation).

At the same time, it is of undoubted scientific interest to revise these approaches, improve the previously developed methodology and adapt it to sectors of industry (both extractive and manufacturing), as well as conduct an actual evaluation and rank industries recommended for creation (including relocation) in near space. This study is addressed to solving these problems.

Literature Review

In [6], based on the statistical data [7], they analyzed individual indicators of human development related to natural, environmental and industrial components on a global scale since 1990. This is the general situation and trends that have been developed to date: "The number of people living on Earth has increased by almost 1.5 times over the past 30 years, while the increase of the share in total energy consumption and carbon dioxide emissions (per capita) has become still greater; the added value in industry has almost doubled (together with the ever-increasing volumes of industrial production). This has resulted in a significant reduction in the area of arable land and forests. In spite of numerous remedial (recreational) activities undertaken by governments and international organizations, it is impossible to stop this trend" [6].

Thus, the only possible reasonable and feasible scenario for saving mankind from imminent catastrophic environmental consequences is the industrial development of space.

Back in 1982 a Belarusian engineer A. Unitsky conducted a system analysis in [4] of the inevitability of near space industrialization by the Earth's civilization: "Our industry is adapted to the conditions on Earth, since there was no choice. Space provides it to us. Incredible opportunities are opening up to locate plants and factories in weightlessness, deep vacuum, ultra-low and ultra-high temperatures, enhanced radiation... And these conditions are just around the corner – a few hundred kilometers away. Most of manufacturing processes will be much more effective and efficient in outer space and mass production will rise to a new qualitative level. Just as now the factory shops are relocated outside the residential area, in the future the main component of production will be moved outside our common home – the Earth, which will be transformed into an evergreen place for life, education and recreation of earthlings. To accomplish all this, geocosmic transport must not only have an annual capacity of billions of tons, but also a low cost of transportation."

In 1983, an American fiction writer and scientist I. Asimov made a prediction for The Stare about the need to develop space based on its advantages: "In fact, projects might even be on the planning boards in 2019 to shift industries into orbit in a wholesale manner. Space... is far more voluminous than Earth's surface is and it is therefore a far more useful repository for the waste that is inseparable from industry. Nor are there living things in space to suffer from the influx of waste. And the waste would not even remain in Earth's vicinity, but would be swept outward far beyond the asteroid belt by the solar wind. Earth will then be in a position to rid itself of the side-effects of industrialization, and yet without actually getting rid of its needed advantages. The factories will be gone, but not far, only a few thousand miles straight up" [8].

In [9] the feasibility of space industrialization and relocation of heavy industries into orbit is also substantiated. At the same time, a Canadian engineer E. Kulu, who focuses a considerable part of his scientific research to the study of space and is the owner of a dedicated website, predicts: although no factories have been built and operated in space so far, they will become commonplace by the end of the 2030s [8].

Numerous literary sources and previously presented materials [6] suggest that industry is one of the main polluters of the environment, as it spans all stages of the resource cycle: extraction of natural raw materials (extractive industry), their processing (manufacturing industry), obtaining the finished product and return of industrial waste to the environment.

In addition, various sectors and directions of industry differ significantly from each other in the extent and nature of the environmental impact (atmosphere, hydrosphere, lithosphere). The most negative impact on the living shell of the planet and its natural system – the biosphere – is caused by such sectors as energy, metallurgy, transport and chemical ones [10].

At the same time, the research results of only a few experts (both Belarusian and foreign) trace ideas and individual concepts regarding the scientific and practical problem of selecting sectors of industry for their deployment off-planet. Among such authors, whose writings are publicly available, are A. Unitsky, V. Klyushnikov, N. Sinyuk, A. Babayan, E. Kulu, E. Rush, etc.

However, scientific papers, except for [6], lack methodological approaches to the selection of industries or individual production facilities for creation of the corresponding industries in space.

Furthermore, we should point out that it is the manufacturing industry, associated with the processing of extracted raw materials and energy (and thus with waste products and considerable hazardous emissions), that poses the biggest danger to the biosphere and to all mankind. However, to consider the impact of industry on the biosphere in terms of its manufacturing component alone, does not seem correct and relevant enough. That is why this study gives a complex approach by considering the processes of creation (including those on the basis of relocation) of sectors of industry in near space on the example of extractive and manufacturing industries. This approach is assumed to enable in the future to achieve the maximum effect (from economic, logistical, engineering and other points of view) from the creation of production facilities and entire industries in near space.

This methodology is adapted to sectors of industry (both extractive and manufacturing) and is based on an appropriate assessment, which includes a symbiosis of reliable statistical data for 2017–2020 of the largest country on the planet – the Russian Federation – and information obtained by expert evaluation.

Method Description

The developed methodology for assessing the practicability of creating production facilities in near space is based on a criterial approach relying on the use of eight criteria with a similar number of corresponding indicators (one indicator per criterion) and the unequal influence of their weight coefficients (specific weights) determined by expert method (Table 1).

In general, the values of the specific weights of the criteria under study slightly differ from similar values given and substantiated earlier in [6].

At the same time, taking into account the revision of individual approaches focused on the objectivity of calculations and the scale of data coverage (macro- and meso-levels), as well as the elimination of some redundancies and shortcomings compared to [6], we proposed to introduce three new criteria, with the values of indicators determined through statistical data:

- "Consumption of energy and fuel";
- "Number of organizations in each sector";
- "Involvement of manpower".

However, the criteria "Place of location", "Energy capacity" and "Manufacturing area" used in [6] are excluded for the above reasons.

The extractive and manufacturing industries cited in this article correlate perfectly with the International Standard Industrial Classification of All Economic Activities [11].

Although certain sectors of industry (e.g., production of crude oil and natural gas) are not currently represented by the availability of appropriate raw material in space, this study examined each sector [11], which is aimed at conducting a comprehensive analysis and evaluation, as well as the adequacy (relevance) of the developed methodology.

The calculations carried out through the specified methodology produce an integral value of the practicability index in terms of the deployment of production facilities in near space (hereinafter referred to as practicability index I) and allow a corresponding ranking of industries.

The values of the indicators for four of the eight criteria (1–4) are identified based on reliable general statistical data on the example of the Russian Federation, and for other four (5–8) – by expert analysis, including the analysis of various dedicated references [12–15], the expert position of individual domestic scientists with assigning a value of adjustment factor δ from 0 to 1 (0; 0.5; 1), depending on the relation of the values of sector indicators for criteria 5–8 of to the scale as per Table 1.

It is quite impossible to search for analytical (statistical) world data on the indicators for criteria 1–4 specified in Table 1 in dedicated scientific literature. This fact is confirmed by the absence of such information in response to inquiries (December 2021) to 12 competent international organizations. That is why reliable actual statistical data of the Federal State Statistics Service of the Russian Federation for 2017–2020 were used for the research and evaluation relying on the developed methodology (in terms of criteria 1–4 and their corresponding indicators) [16, 17].

The largest country in the world – the Russian Federation – occupies 11.4 % of the total land area of the planet (including Antarctica). At the same time, the length of the territory from west to east is about 10,000 km, which is comparable to the diameter of the planet (12,700 km). The country is distinguished by a variety of minerals, fuel and energy resources, climatic belts, relief and other natural assets, which creates both suitable conditions for the development of numerous extractive and manufacturing industries, and objective opportunities for analysis by the indicators of criteria 1–4 from Table 1 and the subsequent assessment. In addition, open sources owned by the competent Russian authorities, unlike analytical materials of other major countries of the world, contain a sufficient amount of reliable statistical information in the field of industry after 2016 [18].

Table 1 – Matrix for assessing the practicability of creating production facilities in near space (on the example of extractive and manufacturing industries)

Criterion	Indicator of corresponding criterion, unit of measure		Criterion weight factor K (from 0 to 1)	Adjustment factor δ / the values of indicators (0; 0.5; 1)		
				1	0.5	0
1. Consumption of energy and fuel	Total consumption of energy and fuel in the sector, mln tons of fuel equivalent	The values are determined through statistical data	0.15	See the calculation in Table 2		
2. Hazardous substances emissions	Total hazardous emissions into the atmosphere from stationary emitters in the sector, thous. tons		0.2	See the calculation in Table 2		
3. Number of organizations in each sector	Number of organizations, which are engaged mainly in this sector, thous. units		0.1	See the calculation in Table 2		
4. Involvement of manpower	Average number of employees in the sector, thous. people		0.05	See the calculation in Table 2		
5. Duration of manufacturing process	Average duration of transformation of raw materials (materials and supplies, semi-finished products) into finished products on the Earth in the sector, days	The values are determined through expert analysis	0.1	More than 30	5–30	Less than 5
6. Availability of resources in near space	Assumed availability of resources and raw materials (minerals, solar energy, materials, etc.) in near space necessary for proper production activities in the sector		0.15	In ample supply	Infrequent occurrence (sporadically)	Total absence
7. Quality (competitiveness) of products	Assumed improvement of performance, including service life, of products manufactured (extracted) in space due to natural properties of the environment (weightlessness, deep vacuum, technological purity, etc.)		0.15	Considerable (multiple times / tens of times)	Minor (without significant changes)	Degradation
8. Need for labor force	Rough share of employees, which is reasonable to relocate into near space together with the production facilities to ensure operations (assuming maximum robotization of manufacturing processes), % of the total number of employees		0.1	Less than 20	20–50	More than 50

Based on the developed methodology, practicability index I is calculated through the following original formula:

$$I = ((\sum_{n=1}^{2} K_n \times X_n) + (\sum_{n=3}^{4} K_n \times (1 - X_n)) + (\sum_{n=5}^{8} K_n \times \delta_n)) \times 100\ \%, \quad (1)$$

where I – practicability index (ranging from 0 to 100 %);

n – ordinal number of a criterion (1–8);

K – weight factor of each criterion which reflects its priority in the creation of production facilities in space;

X – normalized values of criteria 1–4 based on the actual values of the corresponding indicators;

δ – adjustment (estimated) factor for criteria 5–8, depending on the expert assignment of values for the sector to a certain category by the scale.

Calculation of the values of practicability index I in terms of adjustment factors for criteria 1–4, with the actual values of the indicators taken from the statistical data of the Russian Federation, was carried out on the basis of one of the most widely used statistical methods for such cases – minimax data normalization method [19].

The normalized value of X for criteria 1–4 and their corresponding indicators is obtained by formula:

$$X_i = \frac{X_{i\,actual} - X_{i\,\min}}{X_{i\,\max} - X_{i\,\min}}, \quad (2)$$

where X_i – actual normalized value of the i^{th} indicator (from 0 to 1);

$X_{i\,actual}$ – actual value of the i^{th} indicator for the sector under consideration during the study period (from 2017 to 2020);

$X_{i\,\min}$, $X_{i\,\max}$ – minimum and maximum values of the i^{th} indicator for the criterion during the same period among all industries.

For indicators calculated by criteria 1 "Consumption of energy and fuel" and 2 "Hazardous substances emissions" we use a direct proportional dependence: the maximum normalized value for each of them (as applied to industries) means the highest degree of feasibility of creating production facilities in space. For criteria 3 "Number of organizations in each sector" and 4 "Involvement of manpower", based on economic and logical considerations, we apply an inverse proportional dependence (the industries which are currently represented on the planet by the minimum number of organizations and employees are mainly recommended for creation in near space).

Outcomes and Analysis

Based on the developed methodology for determining industry-specific practicability index I, we made the appropriate calculations. In this case, we used the summary data from Tables 2 (for criteria 1–4 and their corresponding indicators) and 3 (criteria 5–8 and their corresponding indicators).

Table 2 – Summary of statistical data for 2017–2020 for the Russian Federation and their normalized values for individual indicators (criteria 1–4 in Table 1) by sectors of industry

Subsection* and type (sector) of industry	Value of an indicator by criteria							
	Criterion 1		Criterion 2		Criterion 3		Criterion 4	
	Total consumption of energy and fuel in the sector, mln tons of fuel equivalent**	Normalized value of X_1	Total hazardous emissions into the atmosphere from stationary emitters in the sector, thous. tons	Normalized value of X_2	Number of organizations, which are engaged mainly in this sector, thous. units	Normalized value of X_3	Average number of employees in the sector, thous. people	Normalized value of X_4
1	2	3	4	5	6	7	8	9
Extractive industry								
05. Mining of coal and lignite	20.4	0.076	4,713.5	0.439	0.8	0.014	141.2	0.184
06. Extraction of crude petroleum and natural gas	163.6	0.617	9,631.3	0.896	1.4	0.031	223.3	0.296
07. Mining of metal ores	39.1	0.146	3,773	0.351	3.4	0.082	183.5	0.242
08. Other mining and quarrying	15.6	0.057	498.2	0.046	8.2	0.207	90.2	0.114

End of Table 2

1	2	3	4	5	6	7	8	9
Manufacturing industry								
10. Manufacture of food products	37.8	0.141	752.4	0.07	36.1	0.932	740.3	1
11. Manufacture of beverages	6.4	0.023	146.9	0.013	6.4	0.159	92.9	0.118
12. Manufacture of tobacco products	1.4	0.004	2.2	0	0.3	0	6.2	0
13. Manufacture of textiles	1.6	0.004	17.9	0.001	6.5	0.161	50.3	0.06
14. Manufacture of wearing apparel	1.2	0.003	7	0	13	0.33	73.5	0.092
15. Manufacture of leather and related products	0.4	0	16.9	0.001	1.9	0.044	26.8	0.028
16. Manufacture of wood and of products of wood and cork, except furniture	13.7	0.05	444.9	0.041	22.5	0.577	114.3	0.147
17. Manufacture of paper and paper products	28.2	0.105	369.7	0.034	3.9	0.094	87.5	0.111
18. Printing and reproduction of recorded media	12.5	0.046	12.2	0.001	13.9	0.355	33.7	0.037
19. Manufacture of coke and refined petroleum products	146.9	0.554	2,686.2	0.25	1.3	0.027	128.5	0.167
20. Manufacture of chemicals and chemical products	107.2	0.404	1,552.9	0.144	10.6	0.269	310.2	0.414
21. Manufacture of pharmaceuticals, medicinal chemical and botanical products	11.1	0.04	9.9	0.001	2.1	0.047	71.5	0.089
22. Manufacture of rubber and plastics products	8.4	0.03	81.2	0.007	17.4	0.444	136.4	0.177
23. Manufacture of other non-metallic mineral products	66.8	0.251	1,521.3	0.141	24.1	0.621	298.4	0.398
24. Manufacture of basic metals	264.9	1	10,745.6	1	3.9	0.094	456.7	0.614
25. Manufacture of fabricated metal products, except machinery and equipment	93	0.35	142.3	0.013	38.7	1	456.9	0.614
26. Manufacture of computer, electronic and optical products	7.4	0.027	131.6	0.012	8.9	0.224	357.3	0.478
27. Manufacture of electrical equipment	4.8	0.017	62.2	0.006	8.1	0.204	187.1	0.246
28. Manufacture of machinery and equipment n.e.c.	12.1	0.044	162.6	0.015	16	0.408	303.5	0.405
29. Manufacture of motor vehicles, trailers and semi-trailers	10.2	0.037	107.1	0.01	3.1	0.073	259.4	0.345
30. Manufacture of other transport equipment	16.6	0.061	168	0.015	3.7	0.09	598.7	0.807
31. Manufacture of furniture	5	0.017	28.6	0.002	16.6	0.424	51.7	0.062
32. Other manufacturing	2.4	0.007	9.3	0.001	7.8	0.196	39.5	0.045

* According to [11].

** A ton of fuel equivalent is the energy unit of measure adopted in the Russian Federation, which is equal to 2.93×10^{10} J; it is defined as the amount of energy released during the combustion of a ton of fuel with a calorific capacity of 7,000 kcal/kg (which corresponds to the typical calorific capacity of bituminous coal) [16, 17].

Table 3 – Values of adjustment (estimated) factor δ (0; 0.5; 1) for criteria 5–8 of Table 1, taking into account the expert assignment of values by each sector to a particular category

Subsection* and type (sector) of industry	Values of adjustment factor δ			
	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Extractive industry				
05. Mining of coal and lignite	0	0	0	0
06. Extraction of crude petroleum and natural gas	0.5	0	0	0
07. Mining of metal ores	0.5	1	1	0
08. Other mining and quarrying	0.5	1	1	0
Manufacturing industry				
10. Manufacture of food products	0	0	0.5	1
11. Manufacture of beverages	0	0	0.5	1
12. Manufacture of tobacco products	0	0	0.5	1
13. Manufacture of textiles	0.5	0	0.5	1
14. Manufacture of wearing apparel	0.5	0	0.5	1
15. Manufacture of leather and related products	0.5	0	0.5	1
16. Manufacture of wood and of products of wood and cork, except furniture	0.5	0	0	1
17. Manufacture of paper and paper products	0.5	0	0.5	1
18. Printing and reproduction of recorded media	0	0	0	1
19. Manufacture of coke and refined petroleum products	0	0	0.5	1
20. Manufacture of chemicals and chemical products	0.5	0.5	1	1
21. Manufacture of pharmaceuticals, medicinal chemical and botanical products	0.5	0	1	1
22. Manufacture of rubber and plastics products	0.5	0	1	1
23. Manufacture of other non-metallic mineral products	0.5	0	1	1
24. Manufacture of basic metals	0.5	1	1	0.5
25. Manufacture of fabricated metal products, except machinery and equipment	0.5	1	1	0.5
26. Manufacture of computer, electronic and optical products	0.5	0.5	1	1
27. Manufacture of electrical equipment	0.5	0.5	1	1
28. Manufacture of machinery and equipment n.e.c.	0.5	0.5	1	0.5
29. Manufacture of motor vehicles, trailers and semi-trailers	0.5	0.5	1	0.5
30. Manufacture of other transport equipment	0.5	0.5	1	0.5
31. Manufacture of furniture	0.5	0	0.5	1
32. Other manufacturing	0.5	0.5	0.5	1

* According to [11].

Based on the above formulas (1), (2) and the data of Tables 1–3, we calculated the integral values of practicability index *I* by industries. The corresponding ranking of manufacturing and extractive industries is shown in Figures 1 and 2, respectively.

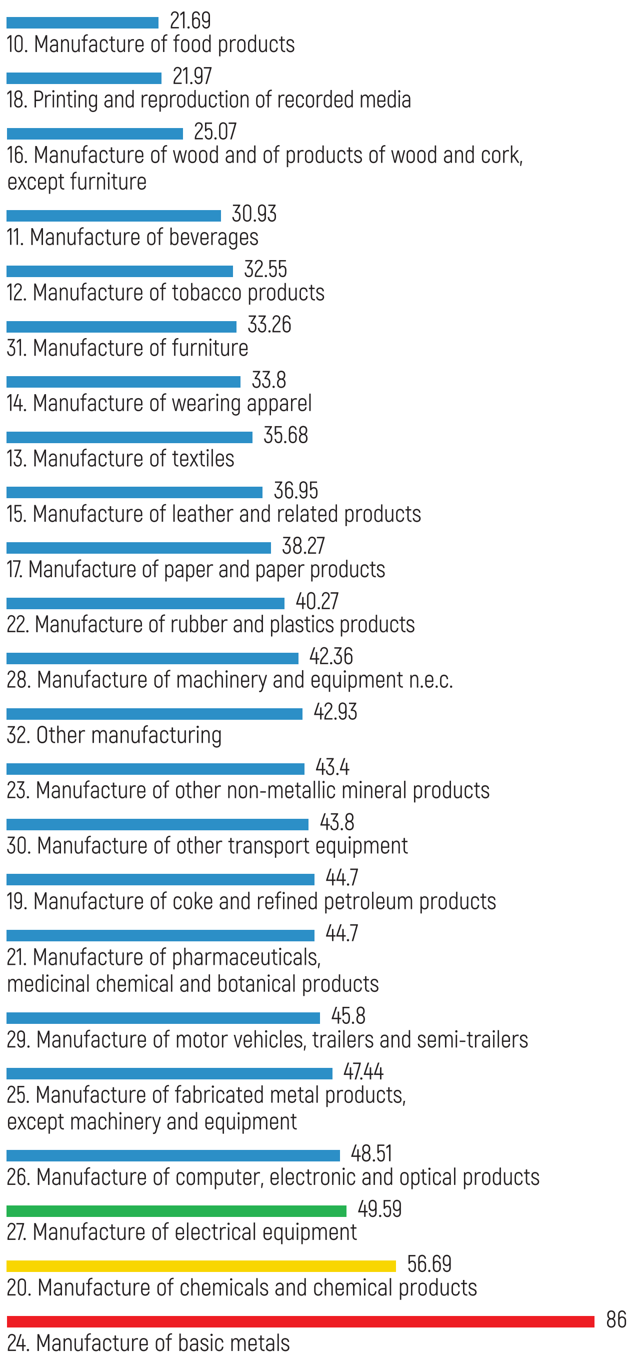

Figure 1 – Ranking of manufacturing industries recommended for creation in near space, depending on practicability index *I*, %

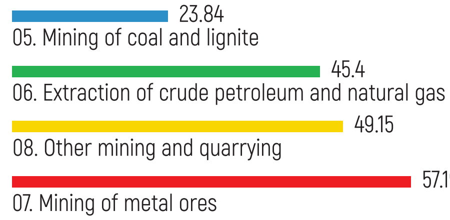

Figure 2 – Ranking of extractive industries recommended for creation in near space, depending on practicability index *I*, %

Conclusions and Future Work

World trends of manufacture and consumption, population growth, hazardous emissions into the environment, and also technocratic and consumptive nature of human development confirm the necessity of the urgent space exploration (and in a non-rocket manner). On this basis we improved the methodology developed earlier in [6] and adapted it to manufacturing and extractive industries: it is supposed to carry out the actual evaluation and ranking of sectors recommended for creation (including relocation) in near space.

As a result, the following manufacturing industries seem the most feasible for creation in near-Earth space:

- manufacture of basic metals (practicability index *I* is 86 %);
- manufacture of chemicals and chemical products (56.69 %);
- manufacture of electrical equipment (49.59 %);
- manufacture of computer, electronic and optical products (48.51 %);
- manufacture of fabricated metal products, except machinery and equipment (47.44 %).

At the same time, manufacture of food products, as well as printing, were identified as those industries that seem premature and not feasible at present in terms of their creation and relocation off-planet.

Based on the results of the evaluation through the above methodology, the following extractive industries seem to be the most feasible in terms of their creation off-planet:

- mining of metal ores (practicability index *I* is 57.19 %);
- other mining and quarrying (49.15 %).

Thus, as part of the forthcoming creation of a new space economy with its unlimited capacities and resources, the results of this study are relevant and can be used by the competent public administration and organizations, including international ones (engaged primarily in the study of space and related problems), as well as by the industrial enterprises to assess their own capabilities and feasibility of creating production facilities (sectors) off-planet in the near future.

The range of environmental problems and related climate change is a severe crisis, and its consequences are becoming more and more pronounced. The application of the proposed methodological approach may soon make it possible to assist in the implementation of a technological breakthrough and the relocation of the most harmful industrial productions into space, thus ensuring a safe environment on Earth. At the same time, thanks to the agreed work of society, humanity will make a leap and create a really green planet, on which the harmony between people and the environment will be restored.

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