Sustainable development of global mineral resources market in Industry 4.0 context

S Hushko¹ J M Botelho² I Maksymova¹ K Slusarenko¹ V Kulishov¹

¹State University of Economics and Technology, Medychna street 16, Kryvyi Rih 50000, Ukraine
²University of Evora, Cardeal Rei Street 6, Evora 70000, Portugal

maksimova_i@kneu.dp.ua

Abstract. The article explores the problems of sustainable development of the natural mineral resources market in the context of digital transformation of the industry. Key trends in the development of the global mineral resources market in economic, ecological, energy and digital dimensions have been identified. The features of the world distribution of raw material base of ore and energy mineral resources in terms of their economic assessment have been studied and the countries - market drivers - have been identified. A model for sustainable development of the mineral resources market and a system of criteria for its assessment in the context of Industry 4.0 have been proposed. In particular, the link between the level of digital technologies and the energy trilemma has been analysed. Based on the results of the calculations, the grouping of the leading countries in the mineral resources market by the level of achievement of sustainable development has been carried out and ways to digitize the mining industry have been outlined.

Keywords: sustainable development, mineral resources, environmental management, measuring sustainability, global mineral resources market, digital economy, Industry 4.0, energy trilemma.

1. Introduction

Despite the dynamic industrial development of the world economy, growing corporate social responsibility and environmental initiatives to find substitutes for exhaustible natural resources, it is the mineral resources of our planet that remain an indispensable basis for the development of the main sphere of material production - industry. It is the mineral resources market that provides the modern industry with energy and all the necessary raw materials, in particular for construction and engineering. However, mineral extraction is an extremely capital-intensive, energy-intensive, technologically complex and environmentally exhausting process. In view of this, ensuring the effectiveness of this process certainly requires the introduction of innovative technologies, which can be ensured by implementing comprehensive Industry 4.0 standards (1, 2). The need for timely transition is also due to the fact that mineral resources are exhaustible in nature as opposed to the endless needs of the global industry for them. In fact, the sustainable development of the world mineral resources involves finding and maintaining a balance between the following areas: economic development; ecological stability; energy stability; innovative development; benefits for society; responsibility of business and government (3, 4).

In this regard, Industry 4.0 is an effective medium for maintaining such a balance and ensuring the sustainable development of the world mineral resources. After all, "Industry 4.0" (the fourth industrial
revolution) inextricably accompanies the modern digital economy and leads to the creation of "smart" industries operating on the principles of energy, environmental and technological stability. Moreover, Industry 4.0 has tremendous potential to transform traditional industry, which until recently was considered quite conservative in the application of digital technologies (5). A set of relevant tools, combined under the name "digital industry", includes big data analysis, machine learning, industrial Internet of Things, augmented reality, 3D printing, robotics and others (6). These technologies are already transforming industries around the world, and their full-scale implementation can have a huge qualitative effect on the international mineral resources market, especially minerals mining and processing (1, 7).

Research on the sustainable development of the mineral resources market in the context of Industry 4.0 requires solving a number of tasks, which are the authors’ focus in this research paper.

Firstly, it is the identification of the shaping trends in the development of the mineral resources market, taking into account the ecological and energy impact on the environment, as well as economic efficiency.

Secondly, it is the formation of a common model for the sustainable development of the mineral resources market in the context of the digital transformation of the industry. This involves defining a mechanism for assessing the capacity and readiness of countries to qualitatively transform their own extractive industries.

Thirdly, it is the definition of strategic ways to improve the balance of sustainable development taking into account the possibilities of transition to Industry 4.0.

This study is based on: analytical and statistical reports of world-renowned organizations on the global raw materials base, technical and economic assessment of stocks, reports on energy trilemma indicators, innovation, competitiveness of industries around the world, digital economy and others.

This study focuses on defining a sustainable development model for the exploitation of such mineral resources as metal ores, coal, oil and natural gas, which account for the lion's share of global mineral exports.

2. Background

2.1. Development trends of the global mineral resources industry: energy, environmental, economic and digital dimensions

As of today, more than two thousand minerals have been identified in the world, but the world industry depends on about 80 known minerals, which form an extremely important raw material base for many industries (8). The demand for minerals is growing worldwide, and therefore the extraction of the Earth's mineral resources is accelerating, with increasing environmental impacts (3, 9). Minerals are an important category of international trade, accounting for 19% of world exports, half of which are energy minerals (10).

Mineral resources management should be based on the paradigm of sustainable development and be consistent with long-term goals and prospects, since the mineral resource base contributes to the development of strategic areas (3, 9, 11):

1. Industrial development (continuous expansion of industrial capacities in the areas of mineral resources mining and processing).
2. High employment level of the population of various qualifications in the industry, accompanied by the creation of a high-tech product.
3. Development of related industries, particularly agriculture, as some mineral resources is the basis for fertilizer production, etc.
4. Energy development.
5. Development of raw material independence of countries and individual regions, strengthening of the national position in the world space.

The analysis allows determining important patterns and trends in the mineral resources market development, which are shaped by natural economic, environmental, energy and technological factors.
Trend 1. High differentiation in the distribution of explored mineral resources reserves in the world, which also have different economic estimates (Table 1).

| Country       | Total position: | Metals and ores: | Energy mineral resources: |
|---------------|----------------|------------------|---------------------------|
|               | Total reserves, estimate, billion USD. | Rank in the world | Metal reserve estimate, billion USD | Rank in the world | Oil and gas reserves estimate, billion USD | Rank in the world | Oil, billion barrels | Rank in the world | Gas, trillion cubic meters | Rank in the world | Coal, mln tonnes | Rank in the world |
| Iran          | 35 300         | 35 300           | 1                         | 157                      | 4                        | 33.6                      | 1 |
| Venezuela     | 34 900         | 34 900           | 2                         | 297.6                    | 1                        | 5.56                      | 8 | 479.4                  | 1 |
| Saudi Arabia  | 33 000         | 33 000           | 3                         | 265.9                    | 2                        | 8.23                      | 6 |
| Russia *      | 32 336         | 18              | 2                         | 30 700                   | 4                        | 87                        | 8 | 32.9                   | 2 | 157                  | 3 |
| USA *         | 29 113         | 1               | 5                         | 28 500                   | 5                        | 35                        | 11| 8.5                    | 5 | 237.2                | 2 |
| Canada *      | 21 200         | 6               | 10                        | 20 200                   | 6                        | 173.9                     | 3 | 1.98                   | 15| 6.5                  |
| Iraq          | 18 000         | 7               | 12                        | 18 000                   | 7                        | 150                       | 5 | 3.6                    | 12|                      |
| Qatar         | 16 400         | 8               | 13                        | 16 400                   | 8                        | 23.9                      | 13| 25.1                   | 3 |
| UAE           | 13 800         | 9               | 14                        | 13 800                   | 9                        | 97.08                     | 7 | 6.09                   | 7 |
| China *       | 13 917         | 10              | 15                        | 13 200                   | 10                       | 17.3                      | 14| 3.1                    | 13| 11.4                 | 10 |
| Australia *   | 10 088         | 12              | 18                        | 5 800                    | 13                       | 3.9                       | 17| 3.8                    | 11| 76.4                 | 4 |
| Turkmenistan  | 9 700          | 13              | 20                        | 9 700                    | 12                       | 0.6                       | 18| 17.5                   | 4 |
| Kazakhstan *  | 7 092          | 14              | 22                        | 6 800                    | 14                       | 30                        | 12| 1.2                    | 18| 33.6                 | 8 |
| India *       | 6 796          | 15              | 23                        | 6 500                    | 15                       | 5.7                       | 16| 1.3                    | 17| 60.6                 | 6 |
| Germany       | 5 003          | 17              | 30                        | 5 003                    | 17                       | 66.7                      | 5 |
| Ukraine *     | 3 074          | 19              | 31                        | 2 558                    | 19                       | 34.1                      | 7 |
| South Africa  | 2 494          | 21              | 32                        | 2 494                    | 1                        | 62                        | 5 |
| Poland        | 1 695          | 22              | 33                        | 1 695                    | 20                       | 22.6                      | 9 |
| Brazil        | 726            | 23              | 34                        | 726                      | 5                        |                          |    |

Note: * - countries that have both explored metal and energy mineral resources; the lead countries for each indicator are highlighted in gray

Source: ratings are calculated by the authors based on statistics (8, 10, 11)

The table shows the countries that have the largest mineral reserves in the world, estimated at the current market value of mineral resources as of 2018. However, it should be emphasized that only 8 countries have minable metal and energy minerals in their subsoil (table 1), and therefore, in the absence of substitutes for these resources, the policy of such countries regarding their mineral deposits will determine production volumes and resource prices for the coming years.

As you can see, the leaders in terms of the availability of energy mineral resources are the countries of the Middle East, where 56% of world oil and 25% of gas are concentrated. The subsoil of Eastern Europe contains 12% of oil, 42% of world gas and 47% of world coal reserves. Latin American countries with 14% of the world oil reserves and North America with 27% of the world coal reserves are also among the leaders.

Powerful mineral resources reserves make it possible to consider these countries as drivers of the global mineral resources market. However, so far, not all these countries are fully developing the deposits located on their territory. For example, according to the latest data from the World Energy Council, available reserves of fossil fuel in the world amount to 1220 billion tons of conventional fuel, while potential reserves are estimated at 4.5 times more (8). In view of this, such resource capacity estimate should be carried out at regular intervals.

Trend 2. Uneven consumption of mineral raw materials. In the world market for mineral resources, economically developed countries are mainly consumers, while developing countries are producers and exporters of natural mineral resources. This "specialization" is explained both by the level of
historical and socio-economic development of the countries of the world, and by the location peculiarities of many types of resources on the planet. Industrialized countries consume more than 60% of non-fuel minerals, 58% of oil and about 50% of natural gas, resulting in a wide gap between production and consumption of mineral resources (3). In the USA it is 20%, and EU countries can only meet their needs by 2/3. The level of Japanese industry mineral resources self-sufficiency is even lower - about 1/3 (3, 4). Developing countries, due to insufficient technological development, consume about 16% of minerals (9). Industrialized countries that do not have large deposits of oil, coal and natural gas are self-sufficient in energy through the international division of labour, selling high value-added products on the world market, while less developed countries have to spend significant financial resources on energy purchases, increasing their external debt.

**Trend 3.** Energy instability. The provision of minerals to the modern world economy is very closely related to the energy problem, since minerals such as oil, gas, coal, uranium, peat, and fuel shale play a leading role in modern energy supply. Although the global supply of energy resources is quite high, the uneven distribution of energy resources, especially the most widely used ones (oil and gas), fluctuations in world energy prices, make the problem of energy supply quite difficult for many countries (especially those that do not have sufficient reserves of their own energy resources).

**Trend 4.** The environmental impact of mining operations significantly disturbs the balance of sustainability factors in the global mineral resources market. Current negative environmental trends in mineral resources extraction are (4, 9, 12):

1. Environmental problems: soil destruction, extinction of flora; conversion of productive land into mountainous and industrial areas; mineral extraction is among the main sources of air, water and soil pollution; extraction involves large consumption of non-renewable energy resources such as coal, oil, natural gas, etc.
2. Rapid depletion of minerals, due to increased demand for mineral resources. As a result, the demand for energy is increasing and more waste is being generated.
3. Environmental and social impacts on residents: dust from mining causes health problems; extraction of some toxic or radioactive minerals is life-threatening; dynamite explosions during mining are very risky because they release very toxic gases; underground mining is more dangerous than surface mining because there is a high probability of accidents caused by landslides, floods, lack of ventilation and the like.

Given this, the supply of minerals to the modern global economy is very closely linked to the energy problem (Trend 3).

**Trend 5.** Variable pricing policies for main mineral resources do not correlate with the rate of extraction of these resources (Figure 1).

![Figure 1](image-url)

**Figure 1** Dynamics of price increases by group of mineral resources (in% compared to the previous year)

Source: calculated by the authors on the basis of (8) and statista.com open source data.
Prices for crude oil, coal, natural gas and iron ore fluctuated rapidly until 2011 (price growth of almost 1.5 times in 2010 after a rapid 60% drop after the 2009 crisis. After 2012 and until 2018, the scope of the price increase did not exceed 20% for energy resources and 50% for iron ore). Oil and natural gas price growth cycles coincide most of the time. On average, oil, coal and gas price peaks follow a three-year cycle. As we can see, the group of metal mineral resources is characterized by greater stability in terms of price growth, after 2011 there are practically no price surges, and the price growth cycle has slowed down from 2 to 4 years.

However, these price increases do not correlate with the volumes of extraction and production of these mineral resources. The annual increase in production volumes is steadily increasing by 10-15% for almost all resources.

**Trend 6. Digital transformation of the global industry and mining industry transition to Industry 4.0 standards.** The analysis shows that the global industrial production sector is developing rapidly, requiring countries to pay more attention to the development of modern facilities and high-tech infrastructure. Today, high-tech industries such as mining and metallurgy actually shape the global production landscape in most countries and can offer a clear path to industrial competitiveness.

However, the transformation of the mineral resources market in line with Industry 4.0 standards requires states to develop and implement a coherent strategy. The following strategic developments for the transition to Industry 4.0 are already presented in the policy documents of leading countries (1, 5, 13, 14):

- The UK Strategy Plan for Industry 2050, Chapter 1 Digital Economy and Industry 4.0: Challenges and Development Prospects;
- The USA National Network for Manufacturing Innovation Program to develop a network of research institutes, aimed at cooperation between academia, industry and government, joint investment, innovation development and the "industrial Internet" in the USA;
- The industrial development plan "New Industrial France" in France is aimed to support 34 industrial projects, including the Factory of the Future, Robotics and others, in coordination with a strategic plan for research, innovation and their transfer;
- The concept of robotics development Robot Revolution in Japan (White Paper on Manufacturing Industries (Monodzukuri)) based on the Industrial Internet of Things;
- Made in China 2025 program published by the State Council of the People's Republic of China in 2015, which provides for the integration of ICT and industrialization.

Industry 4.0 programs have also been launched in the Netherlands, Italy, Belgium and other countries. In Ukraine, "Industry 4.0" is at the initial stage of implementation. We can say that its individual elements are being used rather than the system as a whole.

PwC prepared an analytical report on the metallurgical industry based on 157 interviews with the directors of the respective plants. Average figures for the benefits of digitization based on the results of the survey are as follows: additional revenue - 2.7% per year, cost reduction by 3.2% per year. The main conclusion of the report is that the main benefits are provided by the latest tools of big data analytics, which only 11% of steel mills now have, but in 5 years 83% plan to use them (15).

The outlined trends and patterns directly affect the balance "ecology-energy-economy" in the system of exploitation of mineral resources and necessitate the search for mechanisms to ensure their sustainable development in the era of digital transformation.

2.2. *An empirical model of sustainable development of the mineral resources market in the context of Industry 4.0*

In view of the studied problems of the world mineral resources, the authors proposed a model for the sustainable development of the mineral resources market in the context of the mining industry transition to Industry 4.0. When building such a model, it is necessary to assess the overall potential of the countries that are players in the global mineral resources market, i.e. their readiness and ability to make digital changes in the mineral sector. The authors propose the system of components (criteria) for the sustainable development of mineral resources (Figure 2).
Methods of evaluation. In order to assess the above sustainability components, the values of the respective indicators for the leading countries in the mineral resources market (oil, gas, coal, ore) were collected: the volume of reserves and their economic assessment, the mineral resources management index, the energy trilemic coefficient, the industrial competitiveness coefficient, the economic innovation index and the digital economy indicator. These indicators were then normalized using statistical normalization tools. This normalization made it possible to compare and correlate the indicators of different countries, which were collected in different measurement units. Based on their values, an average final figure was calculated for each country. The resulting totals were then converted to the 100 Scorecard, resulting in sustainable mineral resources development scores for each country (Table 2).

Based on the results of calculations and scoring, it is possible to distinguish such a structure of the world's countries by the level of sustainable development of mineral resources:

Group 1 (100-76 points). Countries with a high level of sustainable mineral resources development that have effective mechanisms for environmentally conscious mining of mineral resources, businesses use corporate social responsibility practices.

Group 2 (75-51 points). Countries with satisfactory level of sustainable mineral resources development. The country has effective strategies in place, but some aspects require improvement. Although the benefits to society from mineral resource development are very likely, there are also negative environmental impacts on the population.

Group 3 (50-26 points). Countries with weak sustainable mineral resources development. Minimal measures have been taken to manage mineral resources; however, they are not accompanied by benefits for the population.

Group 4 (25-0 points). Countries with extremely low level of sustainable mineral resources development. There is virtually no basis for establishing a link between business and people, with the result that society is negatively impacted by the activities of extractive companies.

Let us consider in detail the obtained assessment of mineral resources sustainable development according to the selected criteria of sustainable development.

resource potential and the possibility of entering the mineral resources market. However, low correlation coefficients with other criteria and final scores allow drawing an important conclusion that a system of environmental management is becoming more important for ensuring sustainable development of mineral resources. Thus, some countries with the highest volume and economic assessment of mineral resources (Venezuela, Russia, Iran, and Saudi Arabia) were included into the 2-nd and 3-d groups of countries for relatively low indicators of resource management quality and competitiveness of economies.
Table 2. Assessment of components of mineral resources sustainable development

| Country       | Total reserves estimate billion USD ($X_1$) | Mineral resource management ($X_2$) | Energy trilemma ($X_3$) | Industry competitiveness ($X_4$) | Innovation ($X_5$) | Digital evolution ($X_6$) | Overall assessment, scores |
|---------------|---------------------------------------------|-----------------------------------|--------------------------|---------------------------------|-------------------|---------------------------|-----------------------------|
| The USA       | 0.15                                        | 0.04                              | 0.07                     | 0.02                            | 0.00              | 0.00                      | 95                          |
| Canada        | 0.19                                        | 0.02                              | 0.06                     | 0.17                            | 0.11              | 0.03                      | 90                          |
| Germany       | 0.59                                        | 0.12                              | 0.00                     | 0.04                            | 0.03              | 0.10                      | 85                          |
| Australia     | 0.41                                        | 0.07                              | 0.31                     | 0.43                            | 0.12              | 0.01                      | 77                          |
| China         | 0.33                                        | 0.32                              | 0.27                     | 0.00                            | 0.10              | 0.38                      | 77                          |
| UAE           | 0.30                                        | 0.61                              | 0.29                     | 0.62                            | 0.28              | 0.18                      | 62                          |
| Poland        | 0.78                                        | 0.44                              | 0.34                     | 0.30                            | 0.29              | 0.37                      | 58                          |
| Kuwait        | 0.37                                        | 0.36                              | 0.38                     | 0.64                            | 0.48              | 0.35                      | 57                          |
| Russia        | 0.11                                        | 0.56                              | 0.53                     | 0.66                            | 0.35              | 0.43                      | 56                          |
| Qatar         | 0.26                                        | 0.41                              | 0.32                     | 0.98                            | 0.40              | 0.34                      | 55                          |
| Chile         | 0.85                                        | 0.00                              | 0.35                     | 0.85                            | 0.36              | 0.29                      | 55                          |
| India         | 0.52                                        | 0.08                              | 0.82                     | 0.21                            | 0.45              | 0.63                      | 55                          |
| Saudi Arabia  | 0.07                                        | 0.79                              | 0.40                     | 0.70                            | 0.49              | 0.31                      | 54                          |
| Mexico        | 0.93                                        | 0.20                              | 0.52                     | 0.15                            | 0.44              | 0.54                      | 54                          |
| Brazil        | 0.81                                        | 0.05                              | 0.46                     | 0.60                            | 0.51              | 0.53                      | 51                          |
| South Africa  | 0.74                                        | 0.25                              | 0.79                     | 0.55                            | 0.46              | 0.49                      | 45                          |
| Indonesia     | 0.96                                        | 0.11                              | 0.65                     | 0.38                            | 0.70              | 0.51                      | 45                          |
| Peru          | 0.89                                        | 0.16                              | 0.44                     | 0.79                            | 0.58              | 0.57                      | 43                          |
| Iran          | 0.00                                        | 0.71                              | 0.75                     | 0.77                            | 0.55              | 0.68                      | 43                          |
| Ukraine       | 0.67                                        | 0.49                              | 0.51                     | 0.94                            | 0.33              | 0.56                      | 42                          |
| Kazakhstan    | 0.48                                        | 0.27                              | 0.66                     | 0.83                            | 0.60              | 0.69                      | 41                          |
| Venezuela     | 0.04                                        | 0.85                              | 0.70                     | 0.57                            | 0.58              | 0.81                      | 41                          |
| Iraq          | 0.22                                        | 0.69                              | 0.71                     | 0.74                            | 0.52              | 0.66                      | 41                          |
| Algeria       | 0.63                                        | 0.84                              | 0.58                     | 0.74                            | 0.92              | 0.69                      | 27                          |
| Nigeria       | 0.48                                        | 0.62                              | 1.00                     | 0.79                            | 0.99              | 0.66                      | 24                          |
| Libya         | 0.56                                        | 1.00                              | 0.61                     | 0.72                            | 0.96              | 0.74                      | 24                          |
| Guinea        | 1.00                                        | 0.72                              | 0.99                     | 1.00                            | 1.00              | 1.00                      | 5                           |

Source: calculated by the authors
Note: the lead countries for each indicator are highlighted in gray (normalized value 0-0.2).

Firstly, mineral reserves volume and their valuation play an important role in driving the country's mineral sector. Secondly, an important component of sustainable development of the mineral resources market is a well-balanced policy of natural resources management, which is quite ambiguous in different countries. The Resource Governance Index (RGI) was used for the assessment (16). It measures and evaluates the quality of management in the oil and gas and mining industries of 81 countries that are rich in mineral resources or have the appropriate potential (82% of world oil, 78% of world gas volumes). Ukraine was lucky enough to join RGI for the first time, becoming one of three European countries.
countries, along with the United Kingdom and Norway that were evaluated. However, the not-quitesuccessful 49 out of 100 points allowed Ukraine to rank 44th out of 89 countries in the ranking (16).

Such factors were taken into account when assessing the level of mineral resources management:
1) Value realization (availability of state property among mining companies, state of taxation, licensing, and regional impacts).
2) Revenue management (distribution of revenues from mineral resources extraction, transparency of revenue receipt, existence of environmental impact mitigation funds, etc.).
3) Favorable environment (openness of data, political stability, fight against corruption, government policy regarding extractive companies) (17).

As we can see, all Group 1 countries have high resource management indicators.

It should be noted that extremely low quality indicators of their mineral resources management were demonstrated by the UAE countries, Saudi Arabia, Venezuela, Algeria and Libya, which indicates irresponsibility and intensive exploitation of their own mineral base. This has an extremely negative impact on ensuring sustainable mineral resources development in these countries.

Thirdly, the energy trilemma coefficient was taken into account in modeling the sustainable development of the world mineral resources market. This index is considered a determinant of sustainable development of the fuel and energy sector and reflects the ability of countries to provide stable energy through 3 factors: energy security, energy justice - availability of energy resources, in particular oil and coal, environmental sustainability (17). Environmental sustainability means energy efficiency of supply and demand, development of energy supply from renewable sources and other low-carbon sources (18). This balance indicates the number of points for each measurement and how well the country has managed to balance the energy trilemma.

High indicators of the energy trilemma have been achieved only in 3 countries among the leaders of the mineral resources market (USA, Canada, and Germany). The rest of the countries have certain problems associated with maintaining the balance of the energy trilemma.

The assessment of countries by the energy trilemma index confirms the assumption that countries rich in mineral resources, especially energy minerals (oil, coal, and gas), do not care much about energy conservation and greening of production.

The next driver of sustainable development is the innovativeness of countries' economies, because Industry 4.0 is directly related to the introduction of innovations, technical and intellectual capabilities to create them. It can be assumed that the innovative level of countries rich in mineral resources will affect the degree of production digitalization in the field of mining.

Economy innovativeness depends on a combination of factors (13, 19):
1. The development level of institutions in the country (political, business, scientific, regulatory).
2. Human capital (education and personal development).
3. Infrastructure (social and environmental stability).
4. Market environment (investments, free trade, and credit policy).
5. Business environment (interaction between business, knowledge holders and innovation developers).
6. Knowledge and technological outcomes (knowledge and technology creation).
7. Creativity (the ability to create creative products and services).

In the top 20 most innovative countries there are only 5 commodity countries that are actively engaged in the extraction of mineral resources (the USA, Germany, China, Canada, and Australia).

This trend is reflected in the Digital Evolution Indicator, which is the leading driver of Industry 4.0 promotion in all areas of business (20):
- Terms of supply (digital infrastructure and digital logistics).
- Demand level (ability to carry out transactions using digital technologies, digital financial instruments, mobile applications, digital consumption).
- Institutional development (digital ecosystem, trust in digital tools, transparent competition between IT manufacturers without government pressure, e-government, programs to promote the implementation of digital solutions in industry).
– Innovative changes (innovative developments, startups, availability of innovations, social media, content promotion, etc.).

Among all 28 countries that develop mineral resources, only 3 are in the top twenty in the ranking of digital evolution. It should also be noted that the leaders of the ranking are developed countries, mostly EU countries, as well as eastern stars - Japan, South Korea, and Singapore. These countries are active consumers of mineral products. It can be concluded that such countries with powerful industrial plants for the processing of mineral raw materials are more likely to move to digital standards than countries that are mostly mining them.

The evaluation of paired correlation coefficients (Table 2) suggests that there is a strong link between the sustainable development of the country's mineral resources and indicators such as the energy trilemma index, industrial competitiveness, and the level of the country's digital economy.

It is worth noting that the level of digital transformation directly affects the state of the country's energy trilemma (Fig. 3)

![Figure 3. Impact of digital evolution on the state of the country's energy trilemma (world rating position)](image)

The graph clearly shows that commodity countries such as the USA, Canada, Germany, which have a high level of development of digital technologies in the industry, achieve respectively the best positions in the balance of the energy trilemma as a vivid criterion for sustainable development.

However, it should be emphasized that according to the level of digital evolution, none of the considered mineral-rich countries has risen above the 10th position in the ranking, and therefore the strategy of sustainable development and "smart industry" remains relevant for all countries without exception. Study on the digital transformation of the industry highlights five common objectives of this strategy (21):

1) development of a technical project for business transformation, which begins with a clear strategy for the formation of a modern digital enterprise;
2) creating the necessary conditions to stimulate the use of digital technologies throughout the enterprise;
3) development of a structured approach to risk identification in complex and dynamic ecosystems;
4) building a system of continuous integration of innovations into corporate culture;
5) building flexible operating models that can effectively plan, regulate and control digital processes.
The following general state strategies for the transition of the commodity industry to the digital economy and Industry 4.0 can be distinguished (1, 5, 6):

1) "Digital Transformation" destroys areas of inefficiency in the current economic system in order to free up resources and increase competitiveness. This task is solved with the help of those players who are most interested in progress.

2) "Digital Leap" arises as a result of creating conditions for the growth of new businesses and the rapid development of advanced technologies: big data, artificial intelligence, neural networks, blockchain and more.

3) "Self-digitization" of the state increases the efficiency and transparency of all processes of interaction with the state, simplifies doing business in the country, which creates a broad positive effect on the economy.

4) "Digital reinvestment" is realized as a result of a combination of the first three areas, creates significant added value, reduces transaction costs and creates significant cross-industry effects. The state assumes the role of an investor who invests in the digitalization of strategic areas: education and retraining, infrastructure, health care, conservation of resources, which create a long-term foundation for further development of the digital economy.

For each of the groups of countries (Table 2), this may manifest itself in the following:

Group 1 (high level of readiness for the transition to Industry 4.0 in extractive industries). Countries with large resource, industrial and digital potential. This group includes the United States, Canada, Germany and Australia, which have relatively high rates of innovation, digital evolution and industrial competitiveness. A further strategy for such countries should be to focus on the implementation of Industry 4.0 and the transformation of existing industries into new types of digital factories. In addition, these countries have the highest balance of the energy trilemma among other resource-rich countries.

Group 2 (average readiness level). Countries with high resource and technological potential, but lower levels of innovation and digitalization. This group includes China, which ranks first in terms of industrial competitiveness, has some of the largest deposits of various mineral resources, and does not match the pace of digital transformation of industries. For this group of countries, the priority strategy should be the introduction of digitalization programs, as well as balancing the energy trilemma.

Group 3, 4 (insufficient level of readiness, in need of help). Countries with a high level of resource potential, but a low level of innovation and digital development. These are the countries that should focus on balancing industrial development with environmental impacts, which should be supported by digital transformation programs.

On the other hand, in terms of ensuring the sustainable development of mineral resources, it is advisable to form another Group 5 (high level of readiness for the transition to Industry 4.0 in the processing industry). These are the countries that are in the top 10 in terms of digital evolution and innovation of the economy (Switzerland, Sweden, Denmark, Great Britain, the Netherlands, France, South Korea, Japan), but do not have their own significant deposits of mineral resources. These countries are active consumers of mineral processing products, and therefore an effective strategy for them may be to support digitization projects in mineral-rich countries, which will facilitate the transition of the global mineral resources market to Industry 4.0 standards.

3. Suggestions and conclusions

In general, the sustainable development of the world mineral resources requires implementing comprehensive Industry 4.0 standards into all mining processes. This "smart" industry will be based on the principles of energy, environmental and technological stability.

An important patterns and trends in the mineral resources market development are shaped by natural economic, environmental, energy and technological factors. Among them we could distinguish high differentiation in the distribution of explored mineral resources reserves in the world, which also have different economic estimates; uneven consumption of mineral raw materials; energy instability;
the environmental impact of mining operations; variable pricing policies for main mineral resources; digital transformation of the global industry. Authors proposed a model for the sustainable development of the mineral resources market in the context of the mining industry transition to Industry 4.0. This model is based on the following criteria: country's supply of basic mineral resources; the quality of natural resource management; industrial competitiveness capacity of the country; digital Evolution in Industry; Trilemma Index.

Based on the results of calculations and scoring, it was possible to distinguish four groups of the world's countries by the level of sustainable development of mineral resources. The evaluation of paired correlation coefficients suggests that there is a strong link between the sustainable development of the country's mineral resources and indicators such as the energy trilemma index, industrial competitiveness, and the level of the country's digital economy. Thus, countries which have a high level of development of digital technologies in the industry, achieve respectively the best positions in the balance of the energy trilemma as a vivid criterion for sustainable development.

However, it should be emphasized that according to the level of digital evolution, none of the considered mineral-rich countries has risen above the 10th position in the ranking, and therefore the strategy of sustainable development and "smart industry" remains relevant for all countries without exception.

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