Sustainable Development of the World and Russian Metallurgical Industry

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Abstract: The metallurgical industry has been and remains an important component of the global economy. The importance of metallurgy in the life of mankind is also emphasized by the fact that part of the important stages in the history of mankind was named after the name of the processed metals, namely the Bronze and Iron Ages. A key role in global industrial production lies in the fact that metallurgy provides metals and various alloys to many other industries, including the automotive industry, construction, energy, and mechanical engineering. For example, construction provides up to 6% of Russia's GDP. As for direct employment, it accounts for 9.2% of the total number of people employed in the Russian economy. Thus, metallurgy is a kind of locomotive for the development of the country, pulling other industries along with it. The high level of development of the country's metallurgy makes it possible to provide high-tech raw materials and blanks to such high-tech industries as aircraft manufacturing and the space industry. Also, the production of metals and alloys, taking into account high technologies, is important for the shipbuilding and defense industry of the country. Despite its significant importance, the development of the metallurgical industry is characterized by a number of problems, which are primarily related to the environment, inefficient use of resources, etc. A comprehensive solution to these problems is sustainable development, which allows meeting the needs of society at the current stage, without depriving future generations of the opportunity to meet their future needs. This work is devoted to the issues of sustainable development of the metallurgical industry at the national level.

1 INTRODUCTION

The metallurgical industry has a significant impact on the global economy and the economies of various countries. The main reasons for this are as follows.

Firstly, the metallurgical industry provides the basis for the functioning of other industries. The reason for this is that the metals produced by the metallurgical industry are the basis for many other industries, including automotive, mechanical engineering, production of electronic components, etc. Currently, it is relevant to reuse the products of the metallurgical industry (Pourmehdi, Payda et al, 2020) in order to increase global steel and cast-iron production. The possible negative consequences of problems in the metallurgical industry make the issues of designing the sustainability of logistics supply chains of raw materials and products of the metallurgical industry relevant (Borji, Sayadi, 2023). Modeling processes and simulation make it possible to determine the behavior of the system and decision-making in the process of economic activity of the metallurgical industry (Mohammadi, Sayadi et al., 2022).

Secondly, metallurgy promotes technological innovation. In the course of its activities, the metallurgical industry develops innovative alloys and materials that are used in various innovative industries. Also, in order to reduce costs and ensure the efficiency of metallurgical enterprises, enterprise management must adapt to the best practices in the metallurgical industry (Tizroo, Esmaeili et al., 2017).

Thirdly, the metallurgical industry is one of the largest employers providing millions of people with jobs around the world. Therefore, metallurgical enterprises should take into account environmental and social aspects when forming steel supply chains (Condé, Almeida et al., 2024).

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Fourth, the metallurgical industry is a key element of the economy of various countries, due to its significant contribution to GDP, for Russia it is about 5%, and export potential, since the export of metallurgical industry products can become an important source of income for the state. At the same time, international competition in the field of steel production and marketing can lead to significant negative consequences. For example, the South African steel industry has suffered as a result of competition, which makes it urgent to form new business models and paradigms to improve the economic activities of the metallurgical industry, including in the field of improving supply chain management strategies (Khoza, Mafini et al., 2022).

Fifth, the development of the metallurgical industry leads to the development of transport infrastructure, such as railways, sea and river ports, and energy infrastructure facilities.

The sixth reason for the significant influence of metallurgy on the production of steel, aluminum, copper, titanium and other materials is of significant importance for the military industry and the production of weapons.

The last seventh reason for the importance of the metallurgical industry is that the effective development of the metallurgical industry will ensure sustainable economic development through the introduction of energy-efficient technologies, reducing emissions of harmful substances and worsening working conditions. Therefore, most of the research related to the metallurgical industry is devoted to improving its efficiency and reducing emissions of harmful substances into the atmosphere. Recovery issues

Hydrogen-based applications in low-carbon sustainable iron and steel production are considered in the work (Sun, M., Pang, K. et al., 2024). The reduction of CO2 emissions in China using hydrogen metallurgy is described in the work (Wan, Li et al., 2024). The work is devoted to the implementation of ESG principles in the global and Russian metallurgical industry (Glushakova & Chernikova, 2023), methods and tools of climate finance, including green bonds, green tariffs are considered in the work (Yashalova & Potravny, 2023). The use of production for clean energy production in order to ensure low-carbon development is being considered (Xu, Zheng et al, 2024). The application of the technology of separation and simultaneous extraction of rare earth elements and fluorine in bastnesite concentrates is described in the work (Cen, Bian et al, 2021).

Considering the metallurgical industry, it is impossible not to consider such a branch of the metallurgical industry as ferrous metallurgy, which provides the production of cast iron and steel.

Global steel production is constantly growing, in 1950 steel production was 189 million tons, and in 2022 1,885 million tons, thus steel production increased 9.97 times over 72 years. China is the leader in steel production, with a production volume of 1,018 million tons and a share in global production of 54% of total steel production. Next in terms of production volumes are India, Japan, the USA and Russia. China's steel production exceeds that of India by 8 times, Japan by 11 times, the United States by 12 times, and Russia by 14 times.

Figure 1: World steel production for the period from 1950-2022, mln tons.

At the same time, China, despite significant volumes of steel production, reserves of the main raw material – iron ore, are not enough for steel production in China, currently the proven reserves of iron ore account for 8.3% of the global total. At the same time, the ores mined in China are characterized by a low iron content in them. Iron ore also contains a large amount of harmful impurities. The yield of the concentrate with an iron content of 65% is very insignificant. For example, 1.5 billion tons of crude Chinese ore yield only about 300-400 million tons of concentrate. Previously, China was considered the leader among iron ore mining countries, overtaking countries such as Australia, Brazil, India and Russia in terms of iron ore production, however, the methodology for estimating iron ore production has changed

If we talk about the proven reserves of iron ore, then according to the US Geological Survey (USGS), its proven reserves as of January 1, 2021 amount to 175.5 billion tons. At the same time, the estimated iron content in these ores is 84 billion tons. Global iron ore reserves are estimated at 800 billion tons with

a content of 230 billion tons of iron suitable for processing.

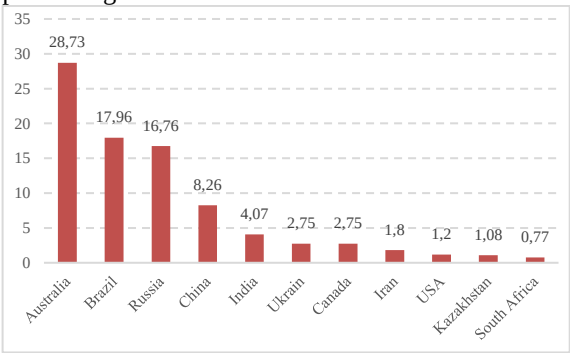

Figure 2: The share of countries in iron ore reserves as of January 1, 2021, in %.

Figure 2 shows that the first place in iron ore reserves is occupied by Australia, which accounts for 28.73% of the world's iron ore reserves. Most of Australia's iron ores have a high iron content of up to 65%. The resulting ore, after the simplest processing methods, which consist in crushing and screening it, is ready for use in metallurgical production. Australia's leading position in iron ore mining makes it the main supplier of this type of raw material to the world market. From Figure 3, it can be seen that 34.62% of the total iron ore is produced in Australia.

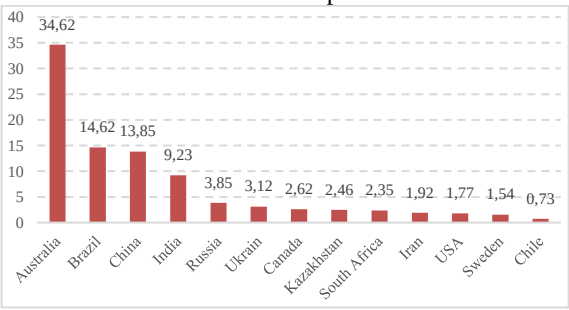

Figure 3: Iron ore production, in %.

At the same time, Australia exports the bulk of the extracted iron ore, more than 90%. The main countries importing iron ore from Australia are China (82.5%), Japan (6.8%), South Korea (6.3%), and India (0.05%).

Brazil is the second country in terms of iron ore reserves and production volumes. Brazil's iron ores are characterized by low levels of harmful impurities such as sulfur, aluminum oxide and silicon dioxide. As for Australia, the main buyer of Brazilian iron ore is China, which consumes 68% of the iron ore supplied by Brazil for export, followed by Malaysia (6.4%), Japan (3.6%), the Netherlands (2%). Unlike Australia, Brazil, in addition to exporting ore, produces steel, occupying a share of 1.8% of global production.

China holds the third place in iron ore production and the fourth place in its reserves. It should be noted that in terms of actual iron ore production, excluding the iron content in it, China is the leader. However, the recalculation of volumes taking into account the iron content, namely to the world standard, implying the presence of 65% iron ore in the extracted rock, gives China only the third place in the world in production. At the same time, it should be noted the poor quality of Chinese iron ores and the presence of a large number of harmful impurities in them. Nevertheless, China ranks first in the world in terms of steel production, see Figure 4.

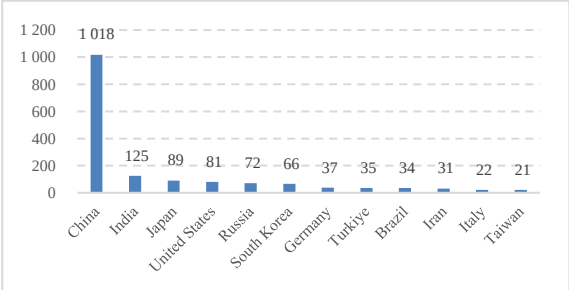

Figure 4: Steel production by the countries of the world million tons.

China is currently implementing a program to reduce the country's dependence on iron ore imports, which includes searching for new deposits in China, expanding the use of scrap metal and buying its own iron ore mining assets.

India ranks fourth in iron ore production with a share of 9.23% in global production. At the same time, India ranks fifth in the world in terms of reserves, and in terms of steel production, the main product of iron ore, second in the world, importing the volume of iron ore necessary for production from countries such as Australia and Brazil. India's iron ore deposits are rich in iron, with a content of 60-68%. At the beginning of the development of the steel industry, most of the extracted iron ore was exported, but after the introduction of protective duties on the export of iron ore, the Indian steel industry began to develop rapidly. If in the 2000s India produced 26.8 million tons of steel, then in 2009 it entered the top four countries in terms of steel production. The Government of India plans to increase the smelting of Indian steel to 300 million tons per year. If India's plan is implemented, it will allow it to maintain its second place in the steel market, and the volume of production will "eat up" part of the market share of other steel producing countries.

Russia ranks fifth in terms of iron ore production, third in terms of its reserves and fifth in steel production. The quality of Russian ores is not high, the iron content in the ore is in the range of 28-34%.

Analyzing the data in Figure 4, it can be concluded that Japan ranks third in the world in the production of cast iron and steel. At the same time, reserves and production of high-quality iron ore with an approximate volume of 228 million tons, for comparison, iron ore reserves in Russia amount to 25 billion tons. The main source of iron ore in Japan is the import of iron ore from other countries. The situation is similar in the United States, which ranks fourth in the world in the production of pig iron and iron ore, while its production is 48 million tons, with a total production of steel and cast iron in the amount of 81 million tons. At the same time, the missing volumes of iron ore are imported from other countries.

To assess the development and prospects of the metallurgical industry, we will group the steel and cast iron producing countries according to the following indicators reflecting production: the country's share in steel production in 2023, in %, the country's share in iron ore production, in%, the increase in steel production over the past thirty-two years, in %, see table 1.

Table 1: A set of indicators for grouping steel and cast-iron producing countries.

Country of manufacture of steel and cast iron	The country's share in steel production in 2023, in %	The country's share in iron ore production, in %	The increase in steel production for the period from 1992 to 2023, in %
…	…	…	…

2 METHODS

The basis for the grouping should be data from the US Geological Survey, as well as the World Steel Association AISBL, which allow us to obtain data on steel production by country of the world million tons, iron ore extraction million tons, these data also allowed us to calculate the indicators indicated in Table 1. The calculation of the increase in steel production will be made for the period from 1992 to 2023 based on data from the US Geological Survey.

The main hypothesis of the study will be that the conducted grouping will allow dividing all steel producing countries into several groups, by analogy with the BCG matrix. These groups will have appropriate characteristics that can be used to determine the directions of sustainable development for each group. To increase the objectivity of grouping, cluster analysis was applied during the study, which is used to group data taking into account their similarities and differences, which are determined by the distance between objects. When conducting cluster analysis, the following methods can be used: k-means, Ward's method, Euclidean distance, k-medians. A review of studies using cluster analysis led to the conclusion that cluster analysis is used in research related to entrepreneurship (Crum, Nelson et al, 2022), retail (Pinto, Salume et al, 2023), marketing research (Punj & Stewart, 1983), the taxonomy of environmental entrepreneurship (Ljungkvist & Andersen, 2021), as well as other studies that allowed the use of cluster analysis in this study.

3 RESULTS

According to the results of the cluster analysis using the k-means method, four groups with clear characteristics were obtained. The first group includes countries with a high share in steel production – at least one percent and with positive growth rates in steel production over the period from 1992 to 2023. This group includes nine steel producing countries, including China, India, Russia, South Korea, Turkey, Brazil, Iran, Taiwan, and Vietnam. At the same time, some countries producing cast iron and steel do not have their own iron ore production, importing the necessary raw materials from other countries. Such countries include South Korea and Taiwan. At the same time, Turkey and Vietnam do not produce enough iron ore to ensure their own steel production, while Brazil produces significant amounts of ore, which are 13 times larger in volume than steel production, sending most of the raw materials for export to other countries. The first group produces 76.18% of the total steel production and 55.48% of the iron ore mined in the world. Characterizing this group, it can be concluded that it and its member countries are a kind of locomotives of the global steel industry, providing the bulk of the increase in global steel production.

The second group of steel producing countries, which includes such countries as Japan, the USA, Germany and Italy, can be described as a group losing its position in the steel production market, but still maintaining its position in the market. The share of

these countries in the market is 12.23%. All countries except the United States do not produce iron ore in significant volumes by exporting from other countries. Iron ore mining in the United States also does not provide steel production. Iron ore production is 48 million tons, with a steel production volume of 81 million tons. The dynamics of steel production by the countries of the second group allows us to characterize them as former leading countries in steel production that are gradually losing their positions in the market, mainly under pressure from the countries of the first group. It should be noted that these countries are the most developed countries that are part of the Group of Seven (G7).

The third group consists of countries that do not play a big role in the global steel market, their share in the global market is less than 1% for each specific country. Overall, this group of 25 countries occupies 7.31%. These countries include Mexico, Egypt, Saudi Arabia, Australia, etc. At the same time, in terms of iron ore production, the group accounts for 34.28% of the total iron ore production in the world, mainly due to Australia, Sweden and Mexico with volumes of 880 million tons, 37 million tons and 23 million tons. At the moment, these countries do not play a significant role in the global steel market, but countries such as Australia, Mexico and Sweden can significantly increase steel production due to existing iron ore reserves. Other countries can also significantly increase steel production both by exporting raw materials and by searching for iron ore reserves on their territory. For example, Saudi Arabia has a program for the development of the steel industry based on export raw materials.

The fourth group is characterized by a low market share in the global steel market of 4.27% and a share in global iron ore production of 8.5%. The main feature of this group is a small share in the global market and a decrease in steel output over the period from 1992 to 2023. This group includes France, Canada, Spain, etc. In general, this group, consisting of twelve countries, represents the countries of western and eastern Europe, as well as South Africa and Kazakhstan. Ukraine is the leader in terms of the rate of decline, which has lost significant volumes of steel production compared to 1992. The United Kingdom and France also lost significant volumes of steel production. At the same time, a number of countries in this group produce significant amounts of iron ore. These include Canada, Ukraine, South Africa, and Kazakhstan. The forecast of the activities of this group of countries allows us to conclude that these countries will continue to stagnate in steel production. At the same time, the countries of this group, especially those with significant iron ore reserves, have a potential opportunity to develop steel production and gain their share of the world market.

4 ANALYSES

The conducted grouping of steel producing countries made it possible to identify four groups of producing countries with specific characteristics describing these groups. By evaluating the characteristics of these groups, they can be brought to the BCG matrix, which allows you to divide the company's product portfolio into four groups "Stars", "Cash Cows", "Question Marks" and "Dogs".

Using the terminology and approach of the BCG matrix, the first group of steel producing countries obtained can be defined as a growth group or "Stars", which has positive growth rates and a significant market share.

The second group, with stagnating production volumes and retaining a significant market share, can be defined as "Cash cows". If production volumes remain stagnant, they may lose market share and move to the "Dogs" group, and with an increase in growth rates to the "Stars" group.

The third group, with positive growth volumes and a relatively small market share, can be attributed to the "Question Mark" group, which, in case of a drop in the growth rate of steel production, can move to the "Dogs" group, and in case of successful development and an increase in market share, to the "Stars" group.

The fourth group, "Dogs", is characterized by negative growth rates and low market share. In the future, with the development of their steel industry, these countries may move into the "Question Mark" group, and if stagnation persists, they will completely lose their competence in the field of steel production.

5 DISCUSSIONS

In accordance with the voiced hypothesis of the study, it was assumed that the conducted grouping would allow dividing all steel producing countries into several groups, by analogy with the BCG matrix. It was also assumed that the groups would have appropriate characteristics that could be used to determine the directions of sustainable development for each group. The analysis showed that the grouping made it possible to divide the steel producing countries into groups by analogy with the BCG

matrix. Let's define the directions of sustainable development for each of the received groups.

The countries of the first group show significant growth and share of the global steel market. The main direction of development of the countries of the first group should be ecology, improvement of working conditions and improvement of the corporate governance system (ESG).

The environmental direction should include improving the quality of atmospheric air in the steel production area, combating climate change, managing the waste disposal process, as well as protecting water resources.

As for occupational safety and industrial safety, first of all, it is the creation of safe working conditions for the company's employees and employees of companies involved in the steel production process. Another important area is occupational safety and industrial safety in the implementation of steel production, including through the reduction of occupational injuries and other measures.

In order to ensure the implementation of sustainable development directions, it is necessary to ensure the improvement of the corporate governance system of steel companies. Therefore, responsibility at the strategic and operational decision-making levels should be defined at the steel industry level. At the government level, it is necessary to adopt regulations governing the process of sustainable development in metallurgical companies.

The second group of countries represents economically developed countries where steel production rates are declining. These countries are unique pioneers of sustainable development, the first to introduce the concept of sustainable development in their metallurgical enterprises. However, the main problem that these countries need to solve for their metallurgical enterprises is to ensure the sustainability of production volumes. In this regard, various incentive measures are possible, related to the introduction of incentive export and protective import duties, investments in more modern methods of steel production, etc.

The third group represents developing metallurgical countries in which the concept of sustainable development can be implemented together with the development of the metallurgical industry using new technologies for the production of cast iron and steel. With the right balance between production volumes and the sustainable development of the industry, it is possible to create a new type of metallurgical enterprises that have a minimal impact on the environment and have maximum efficiency. An example is the development of the US industry in the 19th century, when the US industry, due to newer equipment and technologies, was able to outpace the UK, which had previously been a leader in industrial production. Among the countries of the third group, it is necessary to single out Australia, which is the largest producer of iron ore in the world – 31.71% of all iron ore in the world is mined by Australia. At the same time, Australia's share in steel production is 0.4%. Potentially, Australia, which in addition to iron ore is the largest producer of coal, including coking coal, can become a leader in the production of steel and cast iron. The main obstacle is Australia's environmental policy, which is aimed at reducing carbon dioxide emissions, which will not allow the development of the metallurgical industry at a significant pace. The countries of this group need to apply sustainable industrial development to increase the competitiveness of their industry,

The fourth group represents countries whose market share is minimal, while the growth rate of steel production is negative. If the current trend continues, these countries may disappear as steel producing countries and lose their competence in this area. Sustainable development is possible in these countries, but strong incentive measures are needed to support the national steel industry.

Summing up the results of the study, it can be concluded that the proposed hypothesis of the study has been confirmed, and the conducted grouping of steel and cast-iron producing countries is objective and gives a fairly clear description of the characteristics of each group.

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