ORIGINAL PAPER

DOI: 10.26794/2220-6469-2026-20-1-32-45
UDC 338.45(045)
JEL L11

Complex Analysis of the Value Chain of Russia's Ferrous Metallurgy Based on the 2021 Interindustry Balance

O.E. Navarro[a], A.A. Bykov[b]
[a] LLC "Stalprokat Production Company", Moscow, Russian Federation;
[b] Belarusian State University of Economics, Minsk, Republic of Belarus

ABSTRACT

Objective. The article under consideration presents a comprehensive analysis of the value chain of the Russian ferrous metallurgy industry based on the methodology of the inter-industry balance and input-output tables. The study reveals the economic role of the industry, the structure of production and consumer links, as well as sustainability in view of external constraints. Scenario modeling is utilised to evaluate the consequences of declining exports and the possibilities of compensation through domestic demand and import substitution. **The scientific novelty** of the research lies in its integration of inter-industry analysis with an assessment of the structural adaptability of the industry. The study employs a quantitative assessment of the links between sectors including calculation of full cost coefficients and multipliers. It is specifically applied to the Russian ferrous metallurgy sector in reference to the data of 2021. **The findings** emphasise the necessity for modernisation, in-depth processing and the development of internal industry links. Therefore, the authors suggest measures to be implemented for reducing raw material dependence, increasing added value and ensuring the sustainable development of metallurgy in the context of global transformations.

Keywords: metallurgy; input-output balance; value chain; Russian economy; import substitution

For citation: **Navarro O.E., Bykov A.A. Complex analysis of the value chain of Russia's ferrous metallurgy based on the 2021 interindustry balance. *The World of New Economy*. 2026;20(1):32-45. DOI: 10.26794/2220-6469-2026-20-1-32-45**

INTRODUCTION

Ferrous metallurgy is a key sector of the Russian economy, covering in 2021 nearly 4.4 per cent of gross output and 0.9 per cent of GDP by value added. In the same year, Russia's steel exports accounted for 29.6 million tonnes, leading the country to the 5th position in the global market.[1] Due to a strong dependence on external markets, the sector becomes more vulnerable to sanctions pressure, price fluctuations, as well as global decarbonisation, which requires "green" technologies.[2] Constraints of development also include low value added of exports and high environmental costs.[3] Sanctions imposed after 2014 and 2022 have reduced access to Western markets, which changed its reorientation towards Asia and the Middle East.[4]

The article's research objectives are the following:

- assessment of economic role of the metallurgical sector in the structure of the Russian economy, specifically, analysing its contribution to GDP, exports, and domestic demand;
- analysis of the intersectoral linkages of metallurgy with other sectors of the economy, including determination of key suppliers based on total requirements coefficients (TRC);
- research of the value chain of the metallurgical sector, including the share of domestic and imported resources, as well as gross value added (GVA);
- assessment of the sector's resilience in view of a possible decline in exports and also building scenarios of loss recovery, in view of growing domestic demand or exports in allied sectors;
- elaboration of recommendations for ensuring a sustainable development of metallurgy, including diversification measures of the economy and reduction of dependence on external markets.

Metallurgical production involves the following processes:

- iron ore extraction;
- pellet production;
- coal extraction;
- coke production;
- pig iron production;
- steel production;
- production of long, coiled and flat rolled products (*Fig. 1*).

Theoretical Framework and Methods of Analysis

The input-output model developed by W. Leontief in the 1930s represents the economy as a system of interconnected industries, each of which simultaneously produces output and consumes resources from others [1].

This approach enabling to study complex production linkages and effects, sustains high relevance for the structural analysis of such capital-intensive industries as metallurgy, which are characterised by developed intersectoral flows and significant impacts on related sectors and the environment.

To determine key indicators for the Russian metallurgical industry, we used a methodology developed by Belarusian scientists and described in A.A. Bykov's work [2], based on the Trade in Value Added (TiVA) approach[5] and the use of input-output tables. It was adapted in view of the specific characteristics of metallurgy as a material-intensive and export-oriented industry, which depends on raw material supplies (ore, coal, energy).

The methodology is to assess contribution of metallurgy to GDP formation by calculating the generated value added, as well as by analysing its role in domestic demand (for example, in construction and machinery manufacturing) and in exports, providing a significant share of foreign currency revenues. It allows for evaluation of intersectoral linkages through cost analysis, as well as the *determination of direct and indirect metal consumption* across all components of demand.

[1] URL: https://worldsteel.org/wp-content/uploads/World-Steel-in-Figures-2024.pdf

[2] URL: https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[3] URL: https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/circular-economy-policies-for-steel-decarbonisation_80056a49/4cfb485d-en.pdf; DOI: 10.1787/4cfb485d-en

[4] URL: https://gmk.center/en/posts/how-the-12th-package-of-eu-sanctions-will-affect-the-steel-market/

[5] Trade in Value Added (TiVA) –statistical method that tracks down the contribution of each country and industry to the production of goods and services for global trade.

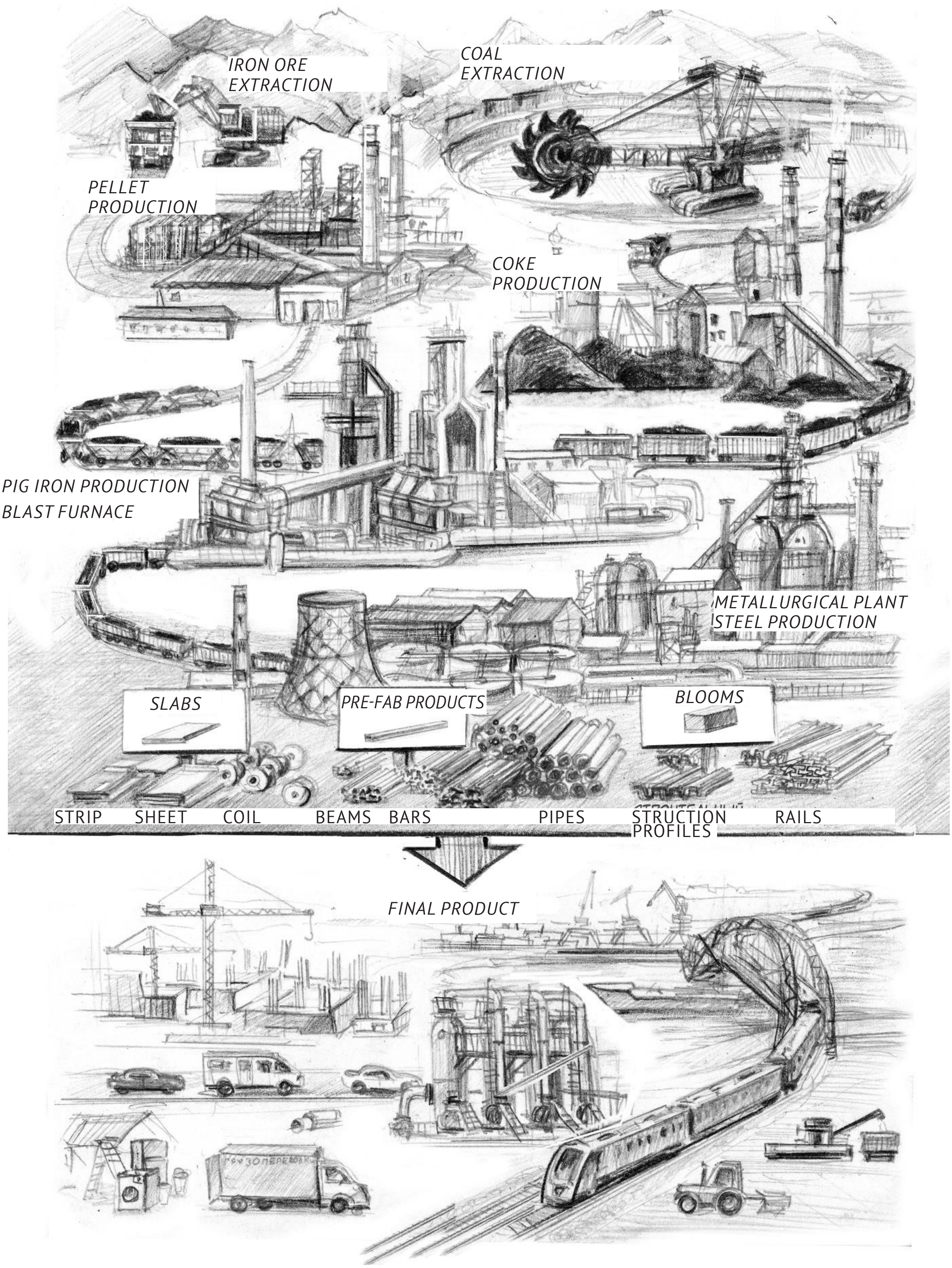

Fig. 1. **Structure of Ferrous Metallurgy Production**

Source: compiled by the authors.

Data Sources

The analysis is based on the input-output tables (IOTs) for 2021, published by Rosstat on 7 February 2025, which provide a complete set of data on intersectoral transactions in Russia.[6]

These tables constitute a comprehensive picture of economic flows. The separation into domestic and imported resources makes it possible to identify the drastic dependence degree of external supplies. Price adjustment with trade margins ensures comparability of data under real market conditions, reflecting end-user costs.[7]

Mathematical Basis of the Input-Output Model

A key tool for analysing the interrelationships between economic sectors is the input-output model. At its core lies the intersectoral flow matrix Z, where element z_{ij} represents the volume of output supplied by sector i to sector j [6, 8].

The total output of sector x_i is defined as the sum of intermediate consumption by other sectors and final demand:

$$x_i = \sum\nolimits_j z_{ij} + y_i, \tag{1}$$

where y_i is the final demand for the output of sector i, including domestic consumption, investment, government spending, and exports.

For example, regarding ferrous metallurgy (OKVED 24.1–24.3):

Total output: x_i = 5,974,117 million Roubles.

Intermediate consumption of sector i output by other sectors:

$$\sum\nolimits_j z_{ij} = 3{,}619{,}192 \text{ million Roubles.}$$

Final demand: y_i = 2,354,925 million Roubles (calculated as the difference between output and intermediate consumption).

Economic rational: the output equation demonstrates that the output of the industry is distributed between intermediate use (for example, supplies to machinery manufacturing) and final demand (including exports and domestic consumption).

This allows for assessing the sectoral contribution to the economy and its role in value chains.

Direct input coefficients a_{ij} are calculated as:

$$a_{ij} = \frac{z_{ij}}{x_i}. \tag{2}$$

where z_{ij} is the intersectoral flow (intermediate supplies): the value of output of sector i used by sector j as intermediate inputs over the period (an element of matrix Z in the IOT);

x_i is the total output of sector j over the period (gross output in basic prices), i.e., the total value of output produced by sector j over the given period.

For example, regarding the iron ores in ferrous metallurgy (OKVED 07.1):

$$a_{07.1,24.1-24.3} = \frac{777\,842}{5\,974\,117} \approx 0.130,$$

where: 777,842 million Roubles refers to the supply of iron ores to ferrous metallurgy; 5,974,117 million Roubles refers to the output of ferrous metallurgy.

Economic rational: the coefficient a_{ij} indicates the volume of resources from sector i required to produce one unit of output in sector j. A value of 0.13 for ores means that for each Rouble of metallurgy's output value, 0.13 Roubles of iron ore output value are required, i.e., a direct technological dependence exists. These coefficients form matrix A, which denotes the economy's cost structure.

Intersectoral Balance Equation

$$x = Ax + y, \tag{3}$$

where x is the output vector;
A is the direct input coefficients matrix;
y is the final demand vector.

$$x = (I - A)^{-1} y, \tag{4}$$

where: I is the identity matrix;

$(I - A)^{-1} = B$ — is the matrix of total requirements coefficients (TRC).

Element b_{ij} of matrix B indicates the total (direct and indirect) inputs from sector i required per unit of final demand in sector j.

[6] URL: https://rosstat.gov.ru/statistics/accounts

[7] Here and below, numerical data are obtained from the IOTs, unless otherwise stated. The authors calculated derived indicators using the formulas provided.

For ferrous metallurgy, the total requirements coefficient: $b_{24.1-24.3}$=1.283.

Economic rational: the matrix accumulates not only the sector's direct inputs (ores, coke, its own electricity) but also indirect chains (ore → coke → metallurgy, multiple repeated feedback use of pre-fab products, etc.). The coefficient (1.283) is an element of the total requirements matrix (the coefficient of total gross output requirements). Its economic interpretation is the following: to satisfy an increase in final demand for ferrous metallurgy products of each Rouble (for example, for export shipment or non-productive consumption), the gross output of metallurgy itself must increase by 1.283 Roubles. Thus, the coefficient reflects the multiplicative self-supply of ferrous metallurgy.

Separation into Domestic and Imported Flows

The direct input matrices are divided into domestic (A_d) and imported (A_m) [2][8]:

$$A_d = Z_d \cdot \widehat{X^{-1}}, \quad A_m = Z_m \cdot \widehat{X^{-1}}, \tag{5}$$

where: Z_d and Z_m — are matrices of domestic and imported flows;

$\widehat{X^{-1}}$ is the diagonal matrix of outputs.

Total requirements:

$$B_d = \left(I - A_d\right)^{-1}, \quad B_m = A_m \cdot B_d. \tag{6}$$

In metallurgy, domestic purchases constitute 4,290,116 million Rubles. (90,7 per cent) and imported purchases make 449,872 million Rubles (9,5 per cent).

Economic rational: the separation of flows enables to assess the sector's dependence on imports. The low import share (9.5 per cent) indicates a high degree of autonomy for metallurgy, which increases its resilience to external shocks. Matrix B_m indicates how imported resources (for instance, equipment) influence output through indirect effects.

Gross Value Added

GVA of sector i is calculated as follows:

$$GVA_i = x_i - \sum_j z_{ji}, \tag{7}$$

where $\sum_j z_{ji}$ is the total intermediate consumption of sector i (the value of products purchased by sector i from all other sectors j for further use of production).

For ferrous metallurgy, GVA = 5,974,117–4,739,988 = 1,234,129 million Roubles (20.66 per cent of output).

Economic rational: GVA represents the sector's net contribution to GDP, including wages, profits and taxes, except intermediate expenses. The relatively low GVA share mirrors the high resource intensity of metallurgy, which limits its ability to generate value added.

Output Multiplier

Output multiplier for sector j:

$$m_j = \sum_i b_{ji}, \tag{8}$$

where b_{ji} is an element of the total requirements matrix (TRC), reflecting the total (direct and indirect) expenses from sector i required per unit of final demand in sector j.

For ferrous metallurgy (OKVED 24.1–24.3) in basic prices (excluding trade and transport markups and net taxes on products), the multiplier totals: $m_{24.1-24.3}$= 2.88.

Economic rational: the value 2.88 indicates that a growth in final demand for ferrous metallurgy products of each Rouble raises total output by nearly 2.88 Roubles. This effect includes output growth not only in metallurgy itself but also among its suppliers: iron ore industry, coke chemistry, electric and thermal power generation, transport, trade, etc., as well as in the links of supply chains.

Numerical Methods

To calculate the total requirements coefficients matrix $B = (I - A)^{-1}$, an *LU* factorisation of matrix $(I - A)$ is performed (decomposing the matrix into the product of lower (*L*) and upper (*U*) triangular matrices for efficient solving of equation systems) [4]:

$$(I - A) = LU. \tag{9}$$

The direct input matrix *A* (113 × 113), which corresponds to the economic activities of 113 types in the IOT-2021, contains nearly half of zero elements, which allows the usage of a Compressed Sparse Row format (CSR) and reduces the computational volume.

[8] URL: https://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF

The input-output balance system $x = Ax + y$ is solved using the iterative Jacobi method:

$$x^{(k+1)} = D^{-1}\left(y-\left(A-D\right)x^{(k)}\right), \quad (10)$$

where: D is the diagonal part of A;
k is the iteration counter;
$x^{(k)}$ is the current solution version at step k.

The greater the number of iterations, the closer $x^{(k)}$ is to the true solution x.

Convergence is guaranteed if the spectral radius $\rho\left(A\right) < 1$. The breakpoint criterion: relative change in solution less than 10^{-6} and in practice 150–300 iterations out of a limit of 1000 are sufficient.

Calculation algorithm:

- Formation of matrix A from IOT data.
- Checking for sparsity and performing *LU*-decomposition.
- Iterative solution using the Jacobi method with convergence control.
- Validation of results by checking output balance.

Value Chain Analysis

The chain covers stages from raw material extraction to disposal [5]. Shares of intermediate consumption (*IC*) are calculated as follows [3]:

The share $IC = \frac{IC_i}{x_i}$, The share $GVA = \frac{GVA_i}{x_i}$, (11)

where: x_i is the output of sector i in basic prices;
IC_i is the intermediate consumption of sector i;
GVA_i is the gross value added of sector i.

For ferrous metallurgy (OKVED 24.1–24.3) in basic prices, output is x_i = 5 974 117 million Roubles, intermediate consumption is IC_i= 4,739,988 million Roubles, and gross value added is *GVAi* = 1,234,129 million Roubles.

Thus, the *IC* share is $\frac{4739988}{5974117} = 0,7934$, equals nearly 79,34 per cent, and the GVA share is $\frac{1234129}{5974117} = 0,2066$, which equals almost 20,66 per cent.

The imported component in the structure of IC equals 449,872 million Roubles, and its share in IC is $\frac{449872}{4739988} = 0,0949$ which is about 9,5 per cent.

The substantial IC share indicates the high resource intensity of the sector, meanwhile the relatively low share of imports reflects the relative autonomy of supply chains.

Calculation algorithm:

- Identifying chain stages: extraction, processing, production, consumption, disposal.
- Calculating output and GVA for each stage based on IOTs.
- Assessment of domestic and imported resource shares.

Assumptions and Limitations

The input-output model assumes fixed coefficients, which restricts the accounting of dynamic effects such as technological changes or price volatility.

As a model for the calculation we used Russia's GDP for 2021 totaling 134,727.5 billion Roubles (per Rosstat data). This ensures consistency with national accounts.

RESULTS OF THE ANALYSIS

Contribution of Ferrous Metallurgy to GDP and Demand Structure: Export Orientation and Domestic Consumption

Ferrous metallurgy (OKVED 24.1–24.3) remains one of the systemically strategic sectors of the Russian economy, bringing a significant contribution to GDP. In 2021, its output amounted to 5,974,117 million Roubles, with final demand distributed between exports (54.03 per cent) and domestic consumption (45.97 per cent), which reflects its significance and vulnerabilities.

Demand structure and export orientation (*Table 1*).

Export dominates in the demand structure: 54.03 per cent (3,227,815 million Roubles), of which 41.72 per cent (2,492,217 million Roubles) is direct exports. 12.31 per cent (735,414 million Roubles) is indirect exports, related to supplies for the production of fabricated metal products (2.30 per cent), machinery manufacturing (3.12 per cent) and other sectors (6.89 per cent). The high share of direct exports reflects the sectoral dependence on global markets with the risks linked to price volatility and geopolitical constraints, including sanctions.

Domestic demand (45.97 per cent, or 2,746,302 million Roubles) includes direct (8.86 per cent, or 529,307 million Roubles), which involves further processing of metal into semi-finished products without a final product (e.g., service metal centres). It also includes indirect demand (37.11 per cent, or 2,216,995 million Roubles) mainly in construction (15.02 per cent, or 897,312 million Roubles) and machinery manufacturing (7.98 per cent, or 476,735 million Roubles). This manifests the core role of metallurgy in infrastructure projects and industrial cooperation. The low share of high-tech segments, such as fabricated metal products (2.69 per cent, or 160,704 million Roubles), displays the need for deeper processing and manufacturing of high-value-added products.

Figure 2 illustrates the distribution of final demand: 54.03 per cent is accounted for direct and indirect exports related to supplies to machinery manufacturing and fabricated metal products. Domestic demand, totaling 45.97 per cent, is concentrated in construction, machinery manufacturing, and services. Such distribution reveals the sector's dual role: on the one hand, it provides a significant foreign currency inflow through exports; on the other on, it supports domestic industries, contributing to industrial cooperation and infrastructure development.

Table 1

Contribution of Ferrous Metallurgy to the Structure of Final Demand, 2021

Indicator	Volume (million of Rubles)	Share in Final Demand (%)
Export:	**3 227 815**	**54.03**
Direct	**2 492 217**	**41.72**
Indirect	**735 414**	**12.31**
Fabricated metal products	137 405	2.3
Machinery manufacturing	186 392	3.12
Other	411 617	6.89
Domestic demand:	**2 746 302**	**45.97**
Direct	**529 307**	**8.86**
Indirect	**2 216 995**	**37.11**
Construction	897 312	15.02
Machinery manufacturing	476 735	7.98
Fabricated metal products	160 704	2.69
Other	682 244	11.42
Total demand	**5 974 117**	**100**

Source: compiled by the authors.

A high export orientation creates risks related to global market volatility and geopolitical factors, including sanctions. To mitigate the risks, it is necessary to diversify sales markets, develop domestic demand, and deeper processing. The low share of high-tech segments, incl. fabricated metal products, requires investments in innovative technologies and modernisation of production. This would increase the share of high-value-added products, strengthening the sector's competitiveness in domestic and external markets.

Concurrently, a significant contribution in construction and machinery manufacturing underscores systemic role of metallurgy in maintaining economic stability. The development of infrastructure projects and industrial cooperation can become drivers of the growth of domestic demand and reduce reliance on exports. State support aimed at stimulating high-tech segments and modernising production capacities can strengthen the sector's position in the long term.

Intersectoral Ties and Suppliers of Ferrous Metallurgy

Analysis of intersectoral linkages reveals the key suppliers of ferrous metallurgy and their role in the economy's integration of the sector. The empirical basis of the research was Russia's symmetric input-output table for 2021, which serves as the basis for calculation of total requirements coefficients for domestic (TRCD) and imported (TRCI) products. The applied analytical approach [6, 7] made it possible to determine the main dependencies, multiplier effects, and advantages for optimal supply chains. Intermediate consumption amounts to 4,739,988 million Roubles, or 79.34 per cent of the overall sectoral output totaling 5,974,117 million Roubles, of which imports account for 449,872 million Roubles, or 9.5 percent of IC, underscoring the high localisation of supplies (*Table 2*). Among the major suppliers are raw material sectors (iron ores, coal, coke), energy, services (transport, scrap metal processing), and machinery manufacturing.

The high share of intermediate consumption (79.24 per cent) indicates an extensive integration of ferrous metallurgy into intersectoral chains, where the key role belongs to extractive industries and intra-sectoral supplies, which emphasises the raw material orientation and strong dependence on them. Trade and transport services ensure efficient logistics, which is vital for the delivery of heavy raw materials and finished products. Scrap metal processing contributes to sustainability and reduces primary raw material costs, which is especially important in the context of requirements of global environment [22]. The low share of imports (8.71 per cent of IC) indicates high localisation, however, dependence on imported equipment (TRCI 0.0096 in machinery manufacturing) and precious metals (TRCI 0.0024) points to opportunities for import substitution. The sector's energy potential requires investment in energy-efficient technologies. Supply chain optimisation is possible through developing production of local equipment, strengthening secondary raw material processing, and improving energy efficiency.

The low import share (8.71 per cent) confirms high localisation. The main imports involved machinery manufacturing (TRCI 0.0096) and precious metals (TRCI 0.0024), indicating potential for import substitution in these categories, especially in manufacturing high-tech equipment.

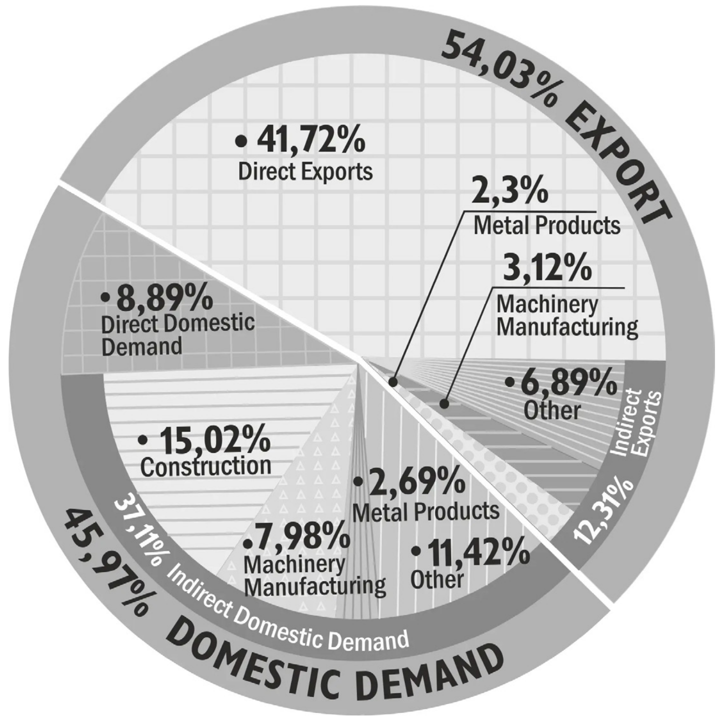

Fig. 2. **Structure of Final Demand for Ferrous Metallurgy Products, 2021**

Source: compiled by the authors.

Analysis of the Value Chain in Russian Ferrous Metallurgy for 2021

The value chain (VC) of Russian ferrous metallurgy covers the stages from raw material extraction to final product manufacturing and distribution. We analysed the structure of intermediate consumption (IC) and gross value added (GVA) of the sector on basis of the input-output tables for 2021 published by Rosstat. The overall output of ferrous metallurgy (OKVED 24.1–24.3) totaled 5,974,117 million Roubles, of which 79.2 per cent is intermediate consumption (4,739,988 million Roubles) and 20.8 per cent is gross value added (1,234,129 million Roubles).

Figure 3 shows the structure of the value chain stages, in view of their shares in total output, based on input-output balance data.

Figure 3 provides the following conclusions:

- The high share of iron ores (11.7 per cent) shows the sector's dependence on stable supplies from the extractive sector, which requires ensuring raw material quality and supply chain resilience.
- The small share of imported precious metals (1.2 per cent) indicates potential for import substitution.
- Partial dependence on imports, included in the 9.5 per cent of total IC imports, indicates the need to develop local equipment production to enhance autonomy.
- The high index of metal production (31.2 per cent) reflects the vertical integration of the sector that uses intermediate products (pre-fab-

Table 2

Ferrous Metallurgy Suppliers

Product / Services	OKVED 2 code	TRCD	TRCI	Flow (million Rubles)
Coal	05	0.0291		173 805
Iron ores	07.1	0.1165		695 851
Coke oven products	19.1	0.0299		178 753
Petroleum products	19.2, 19.3	0.0061		36 240
Refractory products	23.(2,3,4)	0.0061		36 651
Iron, pig iron, steel	24.(1,2,3)	0.2106	0,0283	1 426 986
Precious metals	24.4	0.0123		73 233
Machinery manufacturing and metalworking	25–33	0.0266	0,0096	215 933
Electric power	35.1	0.0254		151 548
Waste collection and treatment (scrap metal)	38	0.0480		286 825
Wholesale trade	46	0.0846		505 392
Transport	49.(1,2,4,5)	0.0289		172 908
Warehousing and storage	52	0.0151		89 921
Services, taxes	Others	0.0779	0,0374	465 384
TOTAL IC		**0.7170**	**0,0753**	**4 739 988**
GVA		**0.2077**		**1 234 129**
TOTAL		**1.0000**		**5 974 117**

Source: compiled by the authors.

ricated products, rolled stock) for further processing. The use of scrap metal contributes to environmental sustainability.

- The logistics sector indicator (4.4 per cent) points to its importance for cost reduction and maintaining competitiveness.
- The high share of trade services (8.5 per cent) determines their role in interaction of producers with markets, especially due to the sector's export orientation.
- Services and taxes (11.5 per cent) make a significant part of IC, which highlights the requirements to optimise non-production costs.
- The low GVA share (20.8 per cent) compared to the economy-wide average level of 40 per cent indicates the sector's limited potential to generate value added, that requires deeper processing and the development of high-tech segments.

The analysis of value chain stages confirms the cornerstone role of ferrous metallurgy in the Russian economy, revealing vulnerabilities due to a high resource intensity and export orientation. Modernisation measures, import substitution, and domestic demand development are necessary for the sector's sustainable development. They would reduce its dependence on external markets and enhance economic efficiency.

Scenario Analysis of Ferrous Metallurgy under Conditions of Export Decline: Justification for Structural Support through the Development of Related Sectors

The export share of ferrous metallurgy (41.7 per cent of the final demand) shapes higher vulnerability of the sector to external limitations. Scenario modelling assesses its resilience to external shocks regarding a 10 per cent reduction in steel exports and it determines strategies to compensate losses by reallocating demand to related sectors or the domestic market.[9] The analysis is based on the 2021 intersectoral balance (Rosstat) using the input-output model and total requirements coefficients (TRC).[10]

Three largest sectoral consumers of ferrous metallurgy products were selected for scenario modelling: construction (15.0 per cent), domestic machinery manufacturing (8.0 per cent), and export-

[9] URL: https://assets.kpmg.com/content/dam/kpmgsites/xx/pdf/2024/09/mining-metals-outlook-2024.pdf; https://www.eurofer.eu/publications/steel-roadmap-for-a-low-carbon-europe-2050/

[10] URL: https://rosstat.gov.ru/statistics/accounts

Scrap Metal 4.8%
Electricity 2.5%

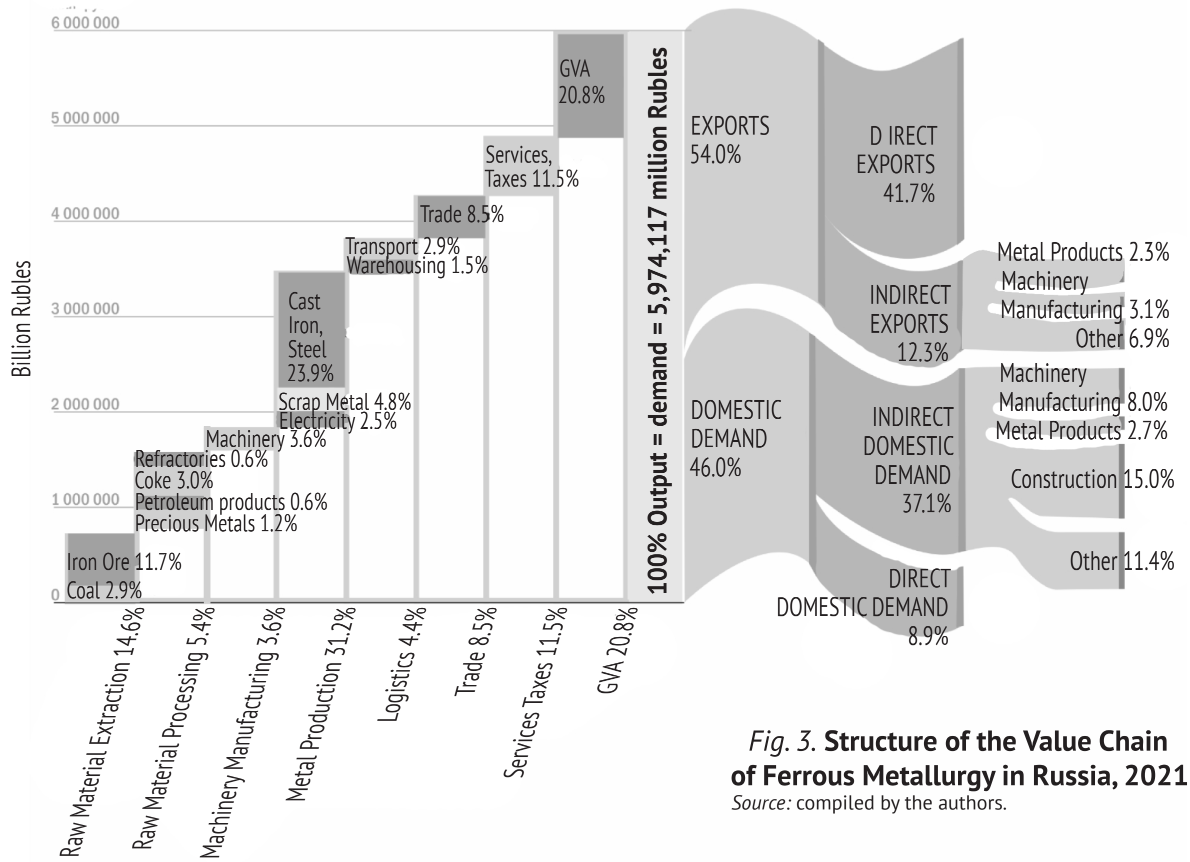

Fig. 3. **Structure of the Value Chain of Ferrous Metallurgy in Russia, 2021**
Source: compiled by the authors.

oriented machinery manufacturing (3.1 per cent).

Parameters and Limitations

Criteria of resilience:

- maintaining the current level of metallurgical output with unchanged production capacity utilisation;
- positive trade balance (ΔTB ⩾ 0).

Three scenarios were reviewed for reallocating the released volume of metal products based on direct input coefficients a_{ij} from the matrix of intersectoral flow:

- S1: increase in machinery manufacturing exports (OKVED 28–30).
- S2: import substitution of machinery manufacturing products in the domestic market.
- S3: expansion of domestic demand in construction (OKVED 41–43).

Initial data (2021):

- metallurgy exports ($Export_{steel}$) — 2,492,216.6 million Roubles;
- metals in machinery manufacturing exports (code 28–30) — 186,328.4 million Roubles;
- metals in national machinery manufacturing (code 28–30) — 476,702.1 million Roubles;
- metals in construction (code 41–43) — 897,316.0 million Roubles;
- indirect input coefficient in construction (metal volume of construction) — $m = 0.0816$ (8.16 %).

Calculation Procedure

1. Metallurgy losses

$$\Delta M = -0.10 \times Export_{steel}, \qquad (12)$$

where the coefficient $(-0{,}10)$ indicates the initial condition of modelling with a 10 per cent export reduction, and the "–" sign indicates the correct direction of the relationship: export reduction → metallurgy losses.

2. The increase in metal consumption of sector k, compensating for |ΔM|, must be equal of the amount of losses:

$$\Delta Metal_k = \left|\Delta M\right|. \qquad (13)$$

3. Relative increase in metal consumption g_k:

$$g_k = \left(\Delta Metal_k / Metal_k^{base}\right) \times 100\%. \qquad (14)$$

4. Sensitivity 'to –1 per cent of steel exports':

$$g_k^{(1\%)} = g_k / 10. \qquad (15)$$

5. Equivalent of output increase:

$$\Delta X_k = \Delta Metal_k / m_k, \qquad (16)$$

where m_k is the total metal intensity of the sector

Table 3

Comparative Analysis of Scenarios for the Development of Ferrous Metallurgy with A 10 Per Cent Reduction in Exports

Indicator	S1: Machinery manufacturing export	S2: Import substitution in machinery manufacturing	S3: Construction
Metallurgy losses, ΔM, million Roubles.	−249 221.65	−249 221.65	−249 221.65
Metals in baseline demand (in million Roubles)	186 328.37	476 702.09	897 316.03
Required increase in metal consumption, ΔMetal (in million Roubles)	+249 221.65	+249 221.65	+249 221.65
Relative increase, %	133.75	52.28	27.78
Sensitivity (−1% of steel), in percentage	13.38	5.23	2.78
Equivalent output increase, ΔX (in million Roubles)	2 199 662	2 335 723	3 054 187
Trade balance changes, ΔTB	≈ 0	+1 040 518	−249 222
Reduction in final imports, (in million Roubles)	0	−1 289 740	0

Source: compiled by the authors.

(weighted mean: 0.1133 for export-oriented machinery manufacturing; 0.1067 for domestic one).

Analytical interpretation

Scenario S1 actually demands doubling the export of high-tech machinery manufacturing products. This is a strategically based, yet a hardly achievable task in the near time, as it requires long-term diversification of sales markets in MENA countries, Latin America, or Southeast Asia and the development of service support. Additional machinery manufacturing export leads to an almost proportionally adequate increase in imports of components and materials.

Scenario S2 ensures a comparable increase in demand for metal products with a twofold smaller relative growth in output. It radically reduces component imports, and makes a positive contribution to the trade balance. Requirements: localising critical components (CNC, hydraulics, bearings) and expanding cooperation with material suppliers.

Scenario S3 imposes the smallest burden on the sector in terms of relative growth, however, it requires a significant financing. The trade balance decreases by the amount of lost revenue from the metallurgical sector if construction materials export does not grow likewise.

The S2+S3 combination becomes the most balanced solution: import substitution in machinery manufacturing provides a structural shift towards high-value-added products, meanwhile infrastructure construction programmes insure a stable domestic demand for steel and maintain capacity utilisation in ferrous metallurgy.

Recommendations for the Development of the Russian Ferrous Metallurgy Sector

The analysis of the value chain of Russian ferrous metallurgy for 2021, made on the basis of input-output tables by Rosstat, has revealed a high export dependence (54.03 per cent of final demand), a low share of gross value added (GVA, 20.8 per cent of output), and significant resource intensity (79.2 per cent intermediate consumption). Global decarbonisation trends, sanctions restrictions, and world market volatility urge the need for structural transformation in the sector. The given scenario modelling and analysis of interjectors' linkages allow for taking measures to enhance the resilience, competitiveness, and technological level of the metallurgical complex, in accordance with the Strategy for the Development of Metallurgy of the Russian Federation until 2030[11] and international practices.

Deepening Processing and Increasing Value Added

The low share of fabricated metal products in final demand (2.69 per cent) and GVA (20.8 per cent) pinpoint the raw material orientation of the sector. It is advisable to transition to high-margin

[11] URL: https://www.garant.ru/products/ipo/prime/doc/405963845/

product manufacturing in the following way:

- establish production clusters in regions with a high concentration of metallurgical assets (Chelyabinsk, Sverdlovsk, Lipetsk regions) for the production of pipe products, prefab structures, and machinery manufacturing components, which are oriented towards the domestic market and exports to EAEU countries [8];
- set up a network of service metal centres for processing rolled products (cutting, bending, coating), which would reduce logistic costs and increase margins by 10–15%.
- introduce investment tax deductions (up to 50 per cent of costs) and subsidies aimed for modernising processing capacities, including equipment for output of high-strength steels and alloys, such as corrosion-resistant grades for the oil and gas industry.[12]

These recommendations correspond with international strategies for increasing value added, as described in the EUROFER roadmap[13] and OECD reports.[14]

Import Substitution and Cooperation with Machinery Manufacturing

Scenario S2 (Import substitution in machinery manufacturing) describes the possibility to compensate 10 per cent reduction in steel exports (+52.3 per cent increase in domestic demand) and improve the trade balance by 1.04 trillion Roubles by means of reducing imports by 1.29 trillion Roubles.

Its implementation requires the following:

- localising the production of metal-intensive components (frames, shafts, housings, bearings) through cooperation between metallurgical holdings (NLMK, MMK, Severstal) and machinery manufacturing enterprises (AvtoVAZ, Uralmash, OMZ, KAMAZ, etc.);
- supporting public-private partnerships in machine tool building, power and transport machinery manufacturing through subsidies for R&D (up to 30 per cent of costs) and product certification, including ISO standards for exports;
- stimulating exports of machinery manufacturing products to EAEU countries, Southeast Asia, and the Middle East through preferential lending and logistics support, focusing on export growth of 20 per cent by 2030 [8].

These steps are consistent with the TiVA methodology and recommendations for the integration of industries within the EAEU framework.[15]

Stimulating Domestic Demand

Construction (15.02 per cent) and machinery manufacturing (7.98 per cent) account for 23 per cent of domestic demand for metal products, making them key drivers for compensating export losses (scenario S3, increase of 27.8 per cent).[16]

For the implementation, it is advisable:

- expand government investment in infrastructure (roads, bridges, ports, trunk networks), where metal structures generate a multiplier effect, increasing demand for steel by 10–15 per cent by 2027;
- simplify certification and provide preferences to manufacturers of construction metal products (e.g., rebar, beams) through fast-track accreditation procedures and priority access to government orders;
- introduce industrial leasing for the purchase of domestic equipment (for instance, construction cranes, agricultural machinery) with a Russian metal content of at least 70 per cent, which would support demand for rolled products.[17]

These measures correspond with the strategic objectives of Russia's socio-economic development until 2027.[18]

Modernisation and Decarbonisation

High-energy intensity (2.54 per cent of intermediate consumption) and the necessity to comply with the EU's Carbon Border Adjustment Mechanism (CBAM) require technological transformation.[19]

---

[12] URL: https://www.economy.gov.ru/material/file/b028b88a60e6ddf67e9fe9c07c4951f0/prognoz_socialno_ekonomicheskogo_razvitiya_rf_2025–2027.pdf

[13] URL: http://www.kremlin.ru/events/state-council/76685

[14] URL: https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/circular-economy-policies-for-steel-decarbonisation_80056a49/4cfb485d-en.pdf; DOI: 10.1787/4cfb485d-en

[15] URL: https://ec.europa.eu/eurostat/documents/3859598/5902113/KS-RA-07-013-EN.PDF

[16] URL: https://www.garant.ru/products/ipo/prime/doc/405963845/

[17] URL: https://www.garant.ru/products/ipo/prime/doc/405963845/

[18] URL: https://www.economy.gov.ru/material/file/b028b88a60e6ddf67e9fe9c07c4951f0/prognoz_socialno_ekonomicheskogo_razvitiya_rf_2025–2027.pdf

[19] URL: https://www.oecd.org/content/dam/oecd/en/publications/

The average carbon footprint of Russian metallurgy (about 2.2 tonnes of CO_2 per tonne of steel) exceeds EU levels (1.5 tonnes CO_2).[20]

Thus, it is advisable:

- implementing low-carbon technologies: direct reduced iron (DRI), electric arc furnace production, and hydrogen-based metallurgy, aiming for a 30 per cent reduction in CO_2 emissions by 2030[21];
- use digital solutions (digital twins) for optimising blast furnace processes, conduct real-time emissions monitoring, and forecast energy consumption by means of AI, which could reduce energy costs by 10–15 per cent [1];
- introduce a national "green steel" certification system integrated with life cycle assessment (LCA) methodology to comply with CBAM requirements and maintain access to EU markets.[22]

Such measures are consistent with the recommendations of the IEA and McKinsey for steel industry decarbonisation.[23]

Development of Secondary Processing

Scrap metal processing (4.8 per cent of intermediate consumption) reduces dependence on primary raw materials and supports ecological balance.

To achieve this, it is advised to:

- set up a network of regional scrap collection and processing centres close to metallurgical plants (e.g., in Magnitogorsk, Lipetsk), integrated with transport infrastructure;
- establish quotas (25–30 per cent) for the use of recycled metal in products for government contracts, which would reduce iron ore demand by 10 per cent;
- support investment in modern technologies of scrap processing, including automated sorting lines and electric arc furnaces with low energy consumption.[24]

reports/2024/12/circular-economy-policies-for-steel-decarbonisation_80056a49/4cfb485d-en.pdf; DOI: 10.1787/4cfb485d-en

[20] URL: https://iea.blob.core.windows.net/assets/eb0c8ec1–3665–4959–97d0–187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[21] URL: https://iea.blob.core.windows.net/assets/eb0c8ec1–3665–4959–97d0–187ceca189a8/Iron_and_Steel_Technology_Roadmap.pdf

[22] URL: https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[23] URL: https://www.mckinsey.com/industries/metals-and-mining/our-insights/decarbonization-challenge-for-steel

[24] URL: https://www.garant.ru/products/ipo/prime/doc/405963845/

Such measures comply with OECD recommendations on the development of a circular economy in metallurgy.[25]

Human Resources and Technological Transformation

The introduction of "Metallurgy 4.0" technologies, digitalisation, and ESG standards requires a highly trained workforce.

For this purpose, it is advisable to:

- establish master's degree programmes in "Digital Metallurgy", "Industrial Automation", and "Emissions Management" at technical universities (e.g., MISIS, UrFU) with emphasis on AI and low-carbon technologies;
- launch a federal programme of engineering retraining in cooperation with the Ministry of Education and Science and major holdings, involving at least 5,000 specialists by 2030;
- create training centres based at metallurgical enterprises (e.g., NLMK, MMK, Severstal, EVRAZ) to integrate science, education, and production, attracting young specialists through internships and grants;
- implement youth-centered programmes, including scholarships and innovation project competitions, to activise an inflow of personnel into the sector.

This approach conforms to the priorities of the Russian Ministry of Education and Science and contributes to technological transformation[26].

CONCLUSIONS

Russia's ferrous metallurgy accounts for 4.4 per cent of the gross output of the economy, while its contribution to GDP and to the national export revenues is 0.9 and 2.38 per cent correspondingly. The sector's export orientation is high: 54.03 per cent of output is directed to external markets, predominantly in the form of semi-finished products (77.20 per cent). Its notable feature is a high localisation of production: imports account for only 9.67 per cent of intermediate consumption. The value chain analysis based on input-output tables of Rosstat revealed a low import dependence and key domestic consumers including construction

[25] URL: https://www.oecd.org/content/dam/oecd/en/publications/reports/2024/12/circular-economy-policies-for-steel-decarbonisation_80056a49/4cfb485d-en.pdf; DOI: 10.1787/4cfb485d-en

[26] URL: https://m.minobrnauki.gov.ru/upload/2024/06/24.06_%D0%98%D1%82%D0%BE%D0%B3%D0%B8_v4%20(3).pdf

(15.02 per cent) and machinery manufacturing (7.98 per cent). However, the sector's resource intensity limits the share of value added, which indicates the need to improve production efficiency.

Sanctions and global decarbonisation trends create challenges for the sector, increasing its vulnerability to external shocks. Scenario analysis showed that a decline in exports could be compensated by the development of machinery manufacturing through import substitution, which would make it possible to sustain production volumes and harmonise the trade balance. To enhance resilience and competitiveness, it is advised to stimulate domestic demand by implementing infrastructure projects, upgrading modern technologies for the production of high-quality steel and deep metal processing. The implementation of the proposed measures would allow for reducing external vulnerability, increase value added, and ensure the sustainable development of Russian metallurgical complex in the context of contemporary economic challenges.

REFERENCES

1. Leontief W. Quantitative Input and Output Relations in the Economic System of the United States. *The Review of Economics and Statistics*. 1936.;18(3):105–125.
2. Bykov A.A., Tolkachev S.A., Parkhimenko V.A., Shablinskaya T.V. China's economic growth in 2010–2017: analysis using input-output methodology and modern monetary theory. *Finance: Theory and Practice*. 2021;25(2):166–184. (In Russ.) DOI: 10.26794/2587-5671-2021-25-2-166-184
3. Miller R.E., Blair P.D. Input-Output Analysis: Foundations and Extensions. — 2nd ed. Cambridge, UK: Cambridge University Press; 2009. 750 p. DOI: 10.1017/CBO9780511626982
4. Ten Raa T. The Economics of Input-Output Analysis. Cambridge: Cambridge University Press; 2005. 212 c. DOI: 10.1017/CBO9780511610783
5. Gereffi G. Global Value Chain Analysis: A Primer. URL: https://dukespace.lib.duke.edu/items/e8010f4b-90c9-4835-bc54-16422bb7efb6
6. Knight D., Emelyanova O., Rostovtseva I. et al. Russian economic report 46 The World Bank. URL: https://documents1.worldbank.org/curated/en/099050011302118976/pdf/P17756206d40310aa0a5e109d6fa60bc55a.pdf
7. Baldwin R., Lopez-Gonzalez J. Supply-Chain Trade: A Portrait of Global Patterns and Several Testable Hypotheses. *The World Economy*. 2015;38(11):1682–1721. DOI: 10.1111/twec.12189
8. Myadzel V.S. Problems and prospects of development of the Russian metallurgy within the EAEU. *Economic Relations*. 2024;14(3):575–584. (In Russ.). DOI: 10.18334/eo.14.3.121375
9. Baldwin R. The Great Convergence: Information Technology and the New Globalization. Cambridge: Harvard University Press; 2016. 344 c.

ABOUT THE AUTHORS

Oleg E. Navarro — Technical Director of LLC "PC Stalprokat", Moscow, Russian Federation
https://orcid.org/0009-0006-8145-1998
Corresponding author:
oleg_navarro@mail.ru

Aliaksei A. Bykov — Dr. Sci. (Econ.), Professor, Vice-Rector for Research, The Belarusian State University of Economics, Minsk, Republic of Belarus
https://orcid.org/0000-0003-2005-9061
bikov_a@bseu.by

Conflicts of Interest Statement: The authors have no conflicts of interest to declare.

The article was received on 26.07.2025; revised on 22.08.2025 and accepted for publication on 10.12.2025. The authors read and approved the final version of the manuscript.