

HOW EFFICIENT AND PROFITABLE IS MINING AND QUARRYING SECTOR COMPARED TO LEADING SERBIAN EXPORT SECTORS IN 2024? EVIDENCE FROM CODAS METHOD

A. Fedajev^{1#}, S. Arsić¹, I. Božić Miljković¹

¹University of Belgrade, Technical Faculty in Bor, Bor, Serbia

Received: April 20, 2026; Accepted: August 03, 2026

Abstract

This study examines the efficiency and profitability of the mining and quarrying sector (Sector B according to the NACE classification) relative to other leading export-oriented sectors in Serbia in 2024 using a multi-criteria decision-making (MCDM) framework based on the CODAS method. Entropy-derived weights indicate that the accounts receivable turnover ratio is the most influential criterion (0.159), reflecting the greatest intersectoral variation, whereas the fixed assets turnover ratio has the lowest weight (0.108). The mining and quarrying sector ranks first as the most efficient and profitable sector, while professional, scientific, and technical activities rank last. Sensitivity analysis confirms the robustness of the rankings under alternative weighting and methodological scenarios. The findings provide valuable evidence for assessing sectoral competitiveness and supporting strategic policy and investment decisions. They further suggest that the mining sector's high profitability creates opportunities for policy measures that encourage reinvestment in green technologies and environmentally sustainable mining practices.

Key words: mining and quarrying sector, profitability, efficiency, Entropy method, CODAS method.

1. Introduction

In the global economy, the mining and quarrying sector represents one of the fundamental pillars of industrial development and international trade. It provides important raw materials for key downstream industries such as energy, construction, metallurgy, chemicals, transport, and advanced manufacturing, and thus makes an important contribution to output, employment and export revenues in both developed and developing countries. Over the past decade, global trends such as rapid urbanisation, the expansion of renewable energy technologies and battery value chains, digitalisation of production, and the acceleration of the green transition have led to sustained growth in demand for a wide range of metals and mineral commodities [1,2]. At the same time, the mining industry has been exposed to pronounced volatility of commodity prices, increased geopolitical risks and increasingly rigorous environmental, social and governance requirements, which together have significantly affected its risk-return profile and intensified the need for rigorous analysis of firms' efficiency and profitability.

The mining and quarrying sector holds a significant place in Serbia's economy, primarily due to its significant contribution to exports and the gross domestic product. Rich in mineral resources and strategically positioned in the regional market, Serbia is increasingly relying on the mining sector as an important driver of economic growth, regional development, foreign direct investment (FDI), and infrastructure development, and as a means of addressing numerous social and demographic challenges [3]. Over the past decade, the contribution of the mining sector to total commodity exports in Serbia has steadily increased, with metals and mineral products becoming a dominant export category and showing strong potential for further growth due to expanded production capacities and increasing global demand [4]. To illustrate the expansion of the sector over the last decade, Table 1 presents changes in selected indicators of the sector's performance based on data published by Serbian Business Registers Agency for 2015 and 2024 [5,6].

Table 1 clearly indicates that the mining and quarrying sector in Serbia experienced a significant expansion over the last decade. The number of enterprises increased by approximately 293%

#Corresponding author: afedajev@tfbor.bg.ac.rs

Table 1 Changes in selected performance indicators of the mining and quarrying sector over the last decade

Indicators	2015	2024	Index (2024/2015)
Number of enterprises	322	1,266	393.17
Number of employees	21,500	38,324	178.25
Total assets (in RSD)	508,345,425	1,296,609,955	255.06
Equity	239,905,852	753,654,757	314.15
Loss above equity	65,356,775	23,339,602	35.71
Operating income	264,314,427	912,762,152	345.33
Profit before tax	23,738,617	202,325,673	852.31
Net profit	19,011,583	154,863,203	814.57

(almost 4 times), while employment rose by around 78%, reflecting both the entry of new firms and the expansion of production capacity. At the same time, total assets increased by about 155%, and equity more than tripled (approximately 214%), indicating a substantial strengthening of the sector's financial base. Operating income grew by around 245%, while net profit increased by more than 700%, demonstrating a pronounced improvement in overall profitability. Profit before tax also recorded an increase of over 750%, further confirming the sector's exceptional financial performance dynamics. In contrast, losses above equity declined by approximately 64%, suggesting improved financial stability and reduced vulnerability. Overall, these results provide clear evidence that the mining and quarrying sector has undergone a strong structural expansion and profitability surge over the past decade.

From a broader perspective, evaluating the relative profitability and efficiency of various export sectors is an important step in assessing the position of each sector within the country's overall economic structure. Profitability and efficiency are particularly important for the mining sector, given that companies in this sector are characterized by substantial capital investments and high operating costs, as well as significant price fluctuations of metals on the world market. A comparison of the mining sector with other leading export industries is a necessary prerequisite for assessing whether mining generates superior added value relative to the capital employed. Such comparisons provide a clearer understanding of the competitive advantages and limitations of individual sectors, offering policymakers and investors more concrete guidance for allocating support and resources to mitigate business risks. This is particularly valuable in the context of the Serbian economy, which is characterised by limited resources and intersectoral competition for government support [4,7].

This study aims to compare the efficiency and profitability of the mining and quarrying sector with those of nine other leading export sectors in Serbia in 2024, the most recent year for which data are available, using an Multi-Criteria Decision-Making (MCDM) framework. The evaluation is conducted using ratio analysis, with ratios calculated from aggregated financial data obtained from the Serbian Business Registers Agency [6]. The CODAS (Combinative Distance-Based Assessment) method is applied, using objective weights derived from the entropy method. This method is selected because its distance-based evaluation framework offers strong discriminative capability, particularly when differences among alternatives are relatively small. By combining Euclidean and Taxicab distances from the negative ideal solution, the method provides a more nuanced and reliable ranking of sectoral performance. Following the initial ranking, a sensitivity analysis is performed by applying additional MCDM methods to examine the stability and reliability of the results across different methodological frameworks. The expected scientific contribution of this study is twofold. First, it contributes to the limited body of literature applying advanced MCDM techniques to sector-level financial performance analysis in transition economies, particularly in the Western Balkan region. Second, the study offers empirically grounded insights into the relative position of the mining and quarrying sector within Serbia's economic structure, thereby supporting more informed decision-making for policymakers, investors, and industry stakeholders.

2. Literature Review

In the global context, the mining sector faces strong structural challenges that further emphasize its strategic importance. The intensifying green transition, accelerated electrification of transportation, the development of

artificial intelligence, and the expansion of renewable energy sources have led to a substantial increase in the demand for critical minerals, primarily copper and gold. According to estimates from the International Energy Agency [8], the demand for copper could significantly exceed supply by 2035, with an expected deficit of up to 30% due to insufficient investment in new deposits in previous decades. This gap between growing demand and limited supply is already generating strong signals for increased investment in the exploration and development of new deposits, as well as for increasing production at existing ones. The European Union, through the Critical Raw Materials Act, has clearly recognized the need to diversify supply chains and strengthen domestic and regional production of critical raw materials [9], positioning Serbia as a potential key partner in the European context.

Serbia possesses diverse and high-quality mineral resources, among which deposits of copper, gold, silver, lead, and zinc, as well as significant reserves of coal and industrial minerals, are particularly notable. Serbia is therefore regarded as one of the significant mining economies of Southeast Europe. In addition, reserves of lithium and borates are also gaining special strategic value, especially those in the Jadar region of western Serbia, which, according to some estimates, constitute one of the largest European reserves of this mineral. Over the last decade, the mining sector has experienced substantial growth, primarily thanks to the entry of large foreign investors. In recent years, this sector has attracted significant attention from the public and investors due to major investments, particularly in copper and gold mining. These investments clearly indicate mining's potential to further strengthen Serbia's export competitiveness and enhance the country's economic resilience. In this sense, the mining sector is increasingly taking on the characteristics of a strategic pillar of the national economy, whose financial strength and operational efficiency transcend narrow sectoral boundaries and carry broader macroeconomic and geopolitical implications [10,11].

Despite favorable global trends, the mining sector in Serbia faces numerous specific challenges. The most prominent are environmental pressures and strong opposition from local communities and parts of the public to new mining projects. These challenges are not an exclusively local phenomenon. Research shows that the so-called "social license to operate" has become one of the key factors determining the feasibility and financial success of mining projects worldwide, with a lack of local

acceptance potentially leading to project delays, cost overruns, or abandonment, all of which may have direct negative effects on company financial performance [12,13]. The high capital intensity of projects and extended investment cycles further complicate the achievement of stable profitability amid significant fluctuations in metal prices on the global market [14,15]. According to the findings of some studies, mining companies in transition economies are particularly vulnerable to these fluctuations due to a combination of underdeveloped financial hedging instruments, limited mineral portfolio diversification, an unstable macroeconomic environment, an underdeveloped regulatory and institutional framework, limited inspection capacities, high operating costs associated with energy dependence, and the need to align operations with increasingly stringent ESG standards [14].

Previous studies have demonstrated the broad applicability of MCDM methods in the mining sector, particularly in supporting regional development planning, investment decision-making, and resource management by integrating multiple economic, technical, environmental, and risk-related criteria [16-19]. For example, provincial-level studies have applied MCDM techniques to evaluate and rank regions according to their mining development potential, enabling the identification of areas with the strongest comparative advantages for resource-based growth [16]. In addition, hybrid MCDM approaches such as fuzzy DEMATEL-TOPSIS and fuzzy DEMATEL-PROMETHEE have been used to assess investment preferences in the mineral extraction sector, taking into account the productivity of key inputs such as energy, water, and labor, and highlighting the importance of resource efficiency in determining investment attractiveness [17]. Other studies have proposed structured decision-support models, such as AHP-based frameworks, to assist in selecting optimal mining investment alternatives in polymetallic ore deposits by simultaneously considering economic returns, technical feasibility, and environmental impacts [18]. Furthermore, MCDM-based approaches have been developed to prioritize investment risks in mining projects under uncertainty, demonstrating the usefulness of these methods in complex and high-risk decision environments [19]. Collectively, these studies confirm the flexibility and robustness of MCDM methodologies in addressing diverse mining-related decision problems.

While these studies demonstrate the broad applicability of MCDM techniques in the mining sector, they have predominantly focused on regional planning,

investment evaluation, and environmental or risk-related decision-making [20-23], whereas research addressing the comparative economic performance of the mining sector remains relatively scarce. In the Serbian context, some MCDM-based analyses have been conducted using aggregated financial data from the Serbian Business Registers Agency (APR) to evaluate the business performance of entrepreneurs and rank companies by size [24-26]. However, there is still a notable gap regarding a detailed economic assessment of the mining sector and its comparative positioning relative to other leading export sectors. This study aims to fill this gap by applying the CODAS method as an MCDM approach to analyze the economic performance of companies in the mining sector and, through comparative MCDM analysis, determine the sector's relative position in relation to other key export-oriented industries. Assessing the performance of this sector is crucial for understanding its current role and future prospects within the national economy.

3. Data and methodology

The methodological framework adopted in this study is based on an MCDM approach aimed at evaluating and ranking ten leading export sectors in Serbia in 2024 using profitability and efficiency ratios. The MCDM framework provides a structured approach for integrating multiple, potentially conflicting performance criteria into a unified evaluation model, enabling robust cross-sector comparisons and a more comprehensive assessment of financial performance that single-indicator analyses may overlook [21]. Among various MCDM techniques, the CODAS method is employed due to its strong discriminative capability and robustness in handling complex evaluation problems. By incorporating distance-based measures from the negative ideal solution, CODAS enables effective differentiation among alternatives even when performance differences are relatively small [22]. The proposed methodological framework is summarized in Figure 1.

3.1. Data

To assess the profitability and efficiency of ten leading export sectors, eight indicators were chosen, grouped into two main categories: efficiency ratios (accounts receivable turnover ratio - C_1 , average payment period - C_2 , total assets turnover ratio - C_3 , fixed assets turnover ratio - C_4) and profitability ratios

(operating profit margin - C_5 , net profit margin - C_6 , return on assets - C_7 , and return on equity - C_8). The analysis is based on data provided by the Serbian Business Registers Agency, which annually publishes aggregated balance sheets and income statements at the sectoral level, incorporating summary data from all registered enterprises operating in each sector. In this study, data for 2024 are used, as they represent the most recent available data [23]. Similar sets of indicators have been effectively used in previous studies focused on sectoral performance evaluation using MCDM techniques [24-27].

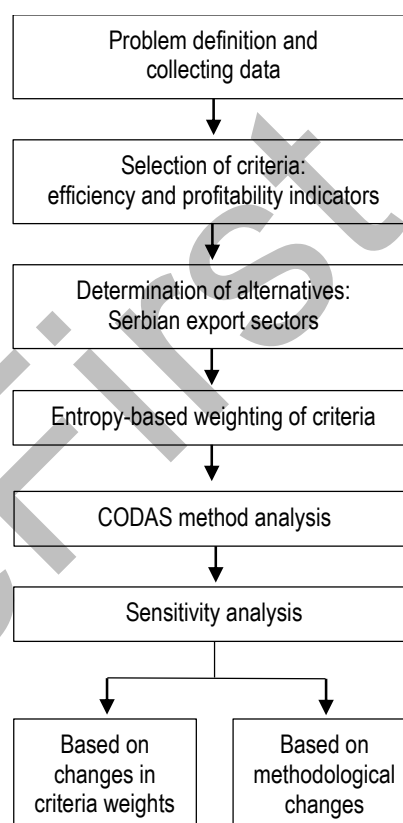


Figure 1 Flowchart of the proposed methodology for ranking export sectors in Serbia

3.2. Entropy method

The weight coefficients are determined objectively using the Shannon entropy method, which quantifies the amount of information contained in the data based on the degree of dispersion among alternatives. In this approach, the decision matrix is first normalized, after which entropy values are calculated for each criterion to

measure the level of uncertainty or disorder in the data distribution [28]. Criteria exhibiting greater variability across alternatives are associated with lower entropy values and, consequently, higher weights, as they provide more discriminative information for the decision-making process. Conversely, criteria with similar values across alternatives contribute less information and are assigned lower importance. By relying exclusively on the intrinsic characteristics of the dataset, the entropy method minimises subjectivity in the weighting process and ensures a data-driven evaluation framework. This feature makes it particularly suitable for the present study, which is based exclusively on quantitative financial indicators obtained from official statistical sources. In contrast to subjective weighting approaches, such as AHP and fuzzy AHP, which require expert judgments and pairwise comparisons, the entropy method derives weights directly from the observed data, thereby enhancing the objectivity and reproducibility of the results. Nevertheless, it should be acknowledged that entropy-based weights reflect only the dispersion of criterion values and do not incorporate expert knowledge regarding the relative importance of the criteria. Despite this limitation, the entropy method has been widely applied to financial performance evaluation using multiple financial ratios [28-30].

3.3. CODAS method

The CODAS (Combinative Distance-based Assessment) method is a multi-criteria decision-making approach used to rank alternatives based on their relative distances from the negative ideal solution. The underlying principle assumes that an alternative is more preferable if it is located farther from the negative ideal point, which represents the worst performance across all criteria [31]. The method employs a combination of Euclidean and Taxicab distance measures to evaluate alternatives. The Euclidean distance is used as the primary measure of separation, while the Taxicab distance serves as a secondary measure to refine the ranking in cases where alternatives exhibit similar Euclidean distances [31,32]. This dual-distance mechanism enhances the discrimination power of the method, particularly in decision problems characterized by small variations in performance values [33]. Compared with other widely used MCDM methods, CODAS provides improved ranking accuracy due to its dual-distance framework. In contrast to TOPSIS, which relies solely on Euclidean distance from both ideal and anti-ideal solutions, CODAS

offers a more refined assessment by incorporating both Euclidean and Taxicab distances from the negative ideal solution. It is also less sensitive to data fluctuations than VIKOR, which may exhibit instability under changes in criteria weights. Furthermore, CODAS achieves stronger discrimination among alternatives compared to aggregation-based methods such as WASPAS and MULTIMOORA, which may produce tied or less distinct rankings. Although CODAS requires the definition of a threshold parameter, which may influence the final results if not appropriately selected, and is computationally more demanding than simpler additive methods such as SAW and WPM, it still provides a robust and reliable ranking framework. The implementation of the CODAS method consists of the following steps [31]:

Step 1. Construct the decision matrix. Form the initial decision matrix $X = [x_{ij}]$, where each element represents the performance value of alternative i with respect to criterion j .

$$X = [x_{ij}]_{n \times m} = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \dots & \dots & \dots & \dots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2. Normalize the decision matrix. Normalize the matrix depending on the type of criteria:

$$\text{For benefit criteria: } n_{ij} = \frac{x_{ij}}{\max x_{ij}} \quad (2)$$

$$\text{For cost criteria: } n_{ij} = \frac{\min x_{ij}}{x_{ij}} \quad (3)$$

Step 3. Construct the weighted normalized matrix. Multiply each normalized value by the corresponding criterion weight:

$$r_{ij} = w_i \cdot n_{ij} \quad (4)$$

Step 4. Determine the negative ideal solution (NIS). The negative ideal solution is defined as:

$$ns = [ns_j]_{1 \times m}; \quad ns_j = \min_i r_{ij} \quad (5)$$

Step 5. Calculate distances from the NIS. Compute two types of distances for each alternative:

$$\text{Euclidean distance: } E_i = \sqrt{\sum_{j=1}^m (r_{ij} - ns_j)^2} \quad (6)$$

$$\text{Taxicab distance: } T_i = \sum_{j=1}^m |r_{ij} - ns_j| \quad (7)$$

Step 6. Construct the relative assessment matrix. Determine the relative assessment between alternatives, shown as follows:

$$h_{ik} = (E_i - E_k) + (\tau(E_i - E_k) \cdot (T_i - T_k)) \quad (8)$$

where $k \in \{1, 2, \dots, n\}$ and τ denotes a threshold function to recognize the equality of the Euclidean distances of two alternatives, and is defined as follows:

$$\tau(x) = \begin{cases} 1 & \text{if } |x| \geq \tau \\ 0 & \text{if } |x| < \tau \end{cases} \quad (9)$$

In this function, τ is the threshold parameter that can be set by decisionmaker. The threshold parameter τ is typically selected within the range of 0.01 - 0.05, with $\tau = 0.02$ frequently adopted as a balanced value in CODAS-based applications [34]. This value was selected as a balanced and commonly used midpoint, ensuring an appropriate trade-off between discrimination sensitivity and ranking stability. Lower values of τ may lead to excessive reliance on Euclidean distances, while higher

values may reduce the method's sensitivity to distinguishing between closely ranked alternatives. To ensure the robustness of the results, a sensitivity analysis is also conducted to examine the impact of varying τ on the final ranking.

Step 7. Calculate the assessment score. For each alternative, compute the overall assessment value:

$$H_i = \sum_{k=1}^n h_{ik} \quad (10)$$

Step 8. Rank the alternatives. Rank alternatives based on H_i values. The alternative with the highest score is considered the best.

Due to its computational efficiency and strong discriminative capability, the CODAS method has been widely applied in various fields, including logistics, energy systems, environmental assessment, and financial performance evaluation [33,35-39].

4. Results and discussion

The empirical analysis is based on the decision matrix presented in Table 2, which includes ten industrial sectors representing the leading export-oriented activities in Serbia.

Table 2 Decision matrix containing performance values of industrial sectors across selected criteria (reproduced from [27]; source data: [6])

Criteria → Alternatives ↓	Efficiency ratios				Profitability ratios			
	Accounts receivables turnover ratio C ₁	Average payment period C ₂	Total assets turnover ratio C ₃	Fixed assets turnover ratio C ₄	Operating profit margin C ₅	Net profit margin C ₆	Return on assets ratio C ₇	Return on equity ratio C ₈
<i>min/max</i>	<i>max</i>	<i>min</i>	<i>max</i>	<i>max</i>	<i>max</i>	<i>max</i>	<i>max</i>	<i>max</i>
A ₁	11.13	32.33	1.0	0.70	22.81	15.74	16.06	19.10
A ₂	5.69	63.32	1.9	0.91	5.42	3.59	4.90	7.15
A ₃	5.46	65.98	0.5	0.41	7.28	2.44	3.02	1.85
A ₄	5.25	68.61	1.2	0.55	7.05	5.43	3.90	8.54
A ₅	6.97	51.63	4.6	1.49	4.47	3.35	6.65	12.19
A ₆	6.87	52.44	0.9	0.69	4.99	2.77	3.43	4.35
A ₇	13.77	26.15	0.9	0.65	6.49	4.46	4.23	6.82
A ₈	4.29	83.83	1.0	0.64	10.82	6.09	6.93	10.04
A ₉	4.38	82.15	0.9	0.55	4.28	1.86	2.37	2.79
A ₁₀	4.62	77.91	1.9	0.98	6.38	4.63	6.24	11.11
<i>w_j</i>	0.159	0.123	0.121	0.108	0.136	0.121	0.119	0.112

The evaluated alternatives comprise A₁ (Mining and quarrying), A₂ (Manufacturing), A₃ (Electricity, gas, steam and air conditioning), A₄ (Construction), A₅ (Wholesale and retail trade, repair of motor vehicles and motorcycles), A₆ (Transportation and storage), A₇ (Accommodation and food service activities), A₈ (Information and communication), A₉ (Professional, scientific and technical activities), and A₁₀ (Administrative and support service activities). These sectors are assessed using selected efficiency and profitability indicators in order to examine their relative performance and positioning within the national economic structure.

The decision matrix was constructed based on financial and statistical data obtained from official national statistical sources and financial statements of the observed sectors. For each alternative, i.e., industrial sector, the values of the selected efficiency and profitability indicators were calculated using standard financial ratio formulas derived from sector-level aggregated data. Specifically, efficiency ratios (C₁-C₄) and profitability ratios (C₅-C₈) were computed to capture different dimensions of sector performance, including asset utilization, liquidity dynamics, and profitability generation capacity.

The objective weights obtained using the entropy method indicate that criterion C₁ (0.159) is the most important criterion, suggesting that the accounts receivable turnover ratio has the greatest informational value and discriminative power among the alternatives. The lowest weight is assigned to C₄ (0.108), indicating relatively lower differences among considered sectors in terms of the fixed assets turnover ratio. These results indicate that the accounts receivable turnover ratio captures the most pronounced differences in operational efficiency among sectors, particularly in terms of liquidity management and the speed of converting sales into cash, which enhances its discriminative power. In contrast, the relatively low weight assigned to fixed assets turnover suggests that sectors exhibit more similar patterns in the utilization of long-term assets, reflecting more stable and structurally determined investment and capacity conditions that limit variability across the considered sectors.

The CODAS method is applied to derive the results used for ranking leading export sectors in Serbia, as shown in Table 3.

The obtained results can be interpreted in the context of the specific role of the mining sector within the Serbian economy and broader global market trends. The leading position of the mining sector (A₁) is primarily driven by its

high profitability, which is consistent with the increasing global demand for critical raw materials and rising commodity prices [6]. In Serbia, this trend has been further reinforced by significant foreign investments and the expansion of production capacities in recent years, confirming the sector's growing importance as a driver of export performance and economic resilience [8]. At the same time, the fact that the mining sector does not consistently achieve the highest values across all efficiency indicators suggests that its strong overall ranking is not solely the result of superior operational efficiency, but also of favorable external market conditions and resource-based advantages. This is in line with findings that emphasize the high capital intensity, long investment cycles, and exposure to price volatility in mining, which can limit efficiency despite strong profitability [14,15]. It should also be acknowledged that the financial performance of the Serbian mining sector is strongly influenced by the dominant position of Serbia Zijin Mining and Serbia Zijin Copper. These two companies generated more than half of the sector's total net profit in 2024. Consequently, the sector-level indicators reported in this study largely capture the performance of these leading companies, reflecting the highly concentrated market structure of the Serbian mining sector, which is dominated by two internationally competitive firms.

Table 3 Ranking results obtained using CODAS method

Alternative	Hi	Rank
A ₁	5.18	1
A ₂	-0.62	6
A ₃	-2.41	9
A ₄	-1.00	7
A ₅	2.20	2
A ₆	-1.44	8
A ₇	1.04	3
A ₈	-0.34	5
A ₉	-2.59	10
A ₁₀	-0.02	4

The exceptionally high profitability of the mining sector identified in this study suggests that the industry possesses sufficient financial capacity to increase investments in environmental protection and cleaner production technologies without compromising its competitiveness. Therefore, rather than relying solely on conventional environmental charges, Serbian

policymakers could consider introducing targeted tax incentives that reward the reinvestment of profits in green technologies, mine rehabilitation, energy efficiency, renewable energy integration, and other measures aimed at mitigating the environmental impacts of mining activities. For example, exempting reinvested profits allocated to certified environmental projects from the corporate income tax base could simultaneously support the transition towards green mining, strengthen the sector's long-term sustainability, and ensure that the economic benefits generated by mining are translated into broader social welfare, particularly for local communities most directly affected by mining operations.

5. Sensitivity analysis

To examine the robustness of the obtained sector rankings with respect to weight definition and methodological variations, a sensitivity analysis was conducted by applying subjective weighting and alternative MCDM methods.

In order to assess the robustness of the results, a sensitivity analysis was first conducted by varying the weights of the evaluation criteria. In this scenario, all criteria were assigned equal weights (0.125), assuming their equal importance in the evaluation process [40]. The differences in objective weights, obtained by entropy method, and subjective weights are presented in Figure 2.

In the next step, the CODAS ranking was recalculated under both weighting scenarios - SC1, based on the objective entropy-derived weights, and SC2, based on equal weights ($w_j = 0.125$) - and the results are presented in Figure 3. The ranking of all ten sectors remained identical in both scenarios, indicating

that the obtained results are not driven by the weighting scheme. A comparison of the entropy-derived weights and the equal weights is presented in Figure 2.

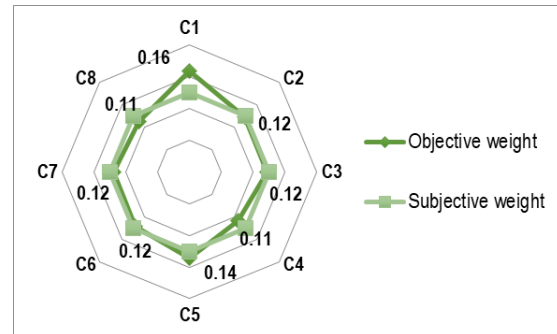


Figure 2 Criteria weight coefficients comparison

In addition to the analysis of weight sensitivity, a further robustness check was performed with respect to the threshold parameter τ used in the CODAS method. Since this parameter may influence the discrimination process between alternatives, its value was varied within the recommended range (0.01 - 0.05) to assess its impact on the final ranking results. The obtained ranking outcomes for different τ values are presented in Table 4.

The results presented in Table 4 demonstrate a high degree of stability in the CODAS ranking outcomes with respect to variations in the threshold parameter τ . Across all tested values of τ , the ranking order of alternatives remains completely unchanged, indicating full rank consistency. Specifically, Alternative A_1 consistently maintains the first position, confirming its dominant performance regardless of the τ value. Similarly, Alternatives A_5 and A_7 consistently occupy the second and third positions, while A_{10} remains stable in the fourth position across all scenarios.

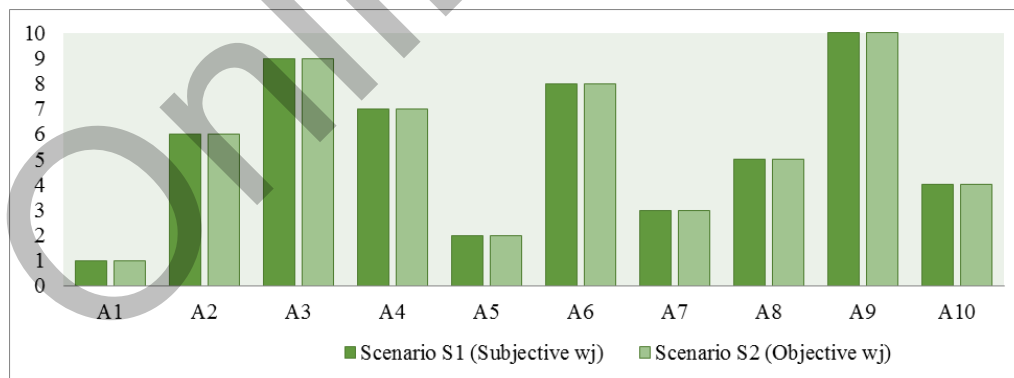


Figure 3 Ranking sectors using CODAS method for scenarios SC1 and SC2

Table 4 Sensitivity analysis of CODAS rankings with respect to the threshold parameter τ

Alternative	$\tau = 0.01$	Hi	$\tau = 0.015$	Hi	$\tau = 0.02$	Hi	$\tau = 0.03$	Hi	$\tau = 0.05$	Hi
A ₁	1	5.18	1	5.18	1	5.18	1	5.18	1	5.18
A ₂	6	-0.60	6	-0.62	6	-0.62	6	-0.64	6	-0.77
A ₃	9	-2.41	9	-2.41	9	-2.41	9	-2.34	9	-2.11
A ₄	7	-1.00	7	-0.97	7	-1.00	7	-0.96	7	-1.11
A ₅	2	2.20	2	2.20	2	2.20	2	2.20	2	2.12
A ₆	8	-1.47	8	-1.47	8	-1.44	8	-1.53	8	-1.36
A ₇	3	1.04	3	1.04	3	1.04	3	1.04	3	0.96
A ₈	5	-0.36	5	-0.35	5	-0.35	5	-0.39	5	-0.37
A ₉	10	-2.59	10	-2.59	10	-2.59	10	-2.51	10	-2.39
A ₁₀	4	0.01	4	-0.02	4	-0.02	4	-0.06	4	-0.16

At the lower end of the ranking, Alternatives A₃ and A₉ consistently retain the last positions, showing no sensitivity to parameter changes. Although minor numerical variations are observed in the CODAS assessment scores, these do not translate into any changes in the final ranking structure. This indicates that the relative distances between alternatives remain sufficiently large to preserve rank stability even under different τ settings.

The next step in sensitivity analysis is application of various MCDM methods, including ARAS, COCOSO, COPRAS, EDAS, MABAC, VIKOR, and TOPSIS. The primary objective of this procedure is to examine the extent to which the ranking of alternatives remains consistent when different methodological frameworks are employed, which is a crucial step in validating the reliability and credibility of the proposed model. Comparative studies have shown that different decision-making techniques and normalization procedures can lead to variations in ranking outcomes, highlighting the importance of cross-method validation [29]. Furthermore, recent research confirms that applying multiple MCDM approaches provides a more reliable assessment of model stability and enhances the credibility of decision-making results [41]. In this study, the application of several well-established MCDM techniques allows for a systematic cross-method comparison, providing additional insight into the sensitivity of sectoral rankings to methodological variations. Such an approach not only enhances the robustness of the results but also ensures that the identified leading sectors maintain their positions regardless of the selected decision model, thereby increasing the practical relevance and credibility of the findings. The results of this comparative analysis are

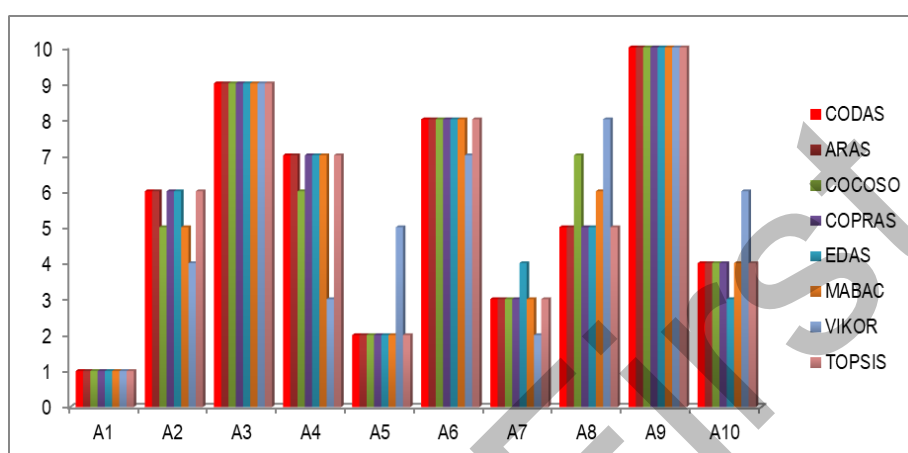
presented in Figure 4. Additionally, Table 5 presents the Spearman rank correlation matrix, which reports pairwise correlation coefficients among the applied MCDM methods in order to quantitatively assess the consistency and robustness of the obtained ranking results.

The results of the Spearman rank correlation analysis in Table 5 indicate a very high level of consistency among the applied MCDM methods. The majority of correlation coefficients exceed 0.95, particularly between ARAS, COPRAS, EDAS, MABAC, and TOPSIS, confirming strong agreement in ranking outcomes. COCOSO also demonstrates strong alignment with most methods, with coefficients above 0.95 in most cases. VIKOR exhibits comparatively lower correlation values (0.70-0.75), although it still indicates a moderate-to-strong positive relationship with other methods. These results confirm the robustness and stability of the proposed ranking structure across different MCDM techniques.

Obtained ranking results are also graphically presented in Figure 4. The results of the sensitivity analysis indicate a high level of consistency in the ranking of alternatives across all applied MCDM methods. Alternative A₁ (Mining and quarrying) consistently ranks first, confirming its dominance and robustness to changes in criteria weights. Alternatives A₂ and A₄ are generally positioned in the upper part of the ranking, with only minor variations across methods, indicating stable and competitive performance. The middle-ranked group, consisting of A₅, A₆, A₇, and A₈, shows moderate variability, reflecting similar performance levels and sensitivity to weighting changes. At the lower end, alternative A₃ consistently ranks last, while A₉ and A₁₀ remain in the lower segment, with slight variations in rank. The ranking structure remains stable, confirming the robustness of the proposed model.

Table 5 Spearman rank correlation matrix of MCDM methods

	ARAS	COCOSO	COPRAS	EDAS	MABAC	VIKOR	TOPSIS
ARAS	1	0.964	1	0.988	0.988	0.733	1
COCOSO	0.964	1	0.964	0.952	0.952	0.7	0.964
COPRAS	1	0.964	1	0.988	0.988	0.733	1
EDAS	0.988	0.952	0.988	1	0.988	0.75	0.988
MABAC	0.988	0.952	0.988	0.988	1	0.75	0.988
VIKOR	0.733	0.7	0.733	0.75	0.75	1	0.733
TOPSIS	1	0.964	1	0.988	0.988	0.733	1

**Figure 4** Sensitivity analysis based on methodological variations

6. Conclusion

The mining and quarrying sector has been gaining increasing importance in the Serbian economy, particularly over the past decade, due to its contribution to export competitiveness of the national economy, regional development, and investment attractiveness. A precise assessment of the sector's efficiency and profitability is therefore essential for guiding strategic decisions made by investors and policymakers. This study employed a combined Entropy-CODAS methodology to evaluate and rank ten leading export-oriented sectors in Serbia, based on eight quantitative financial indicators derived from aggregated data published by the Serbian Business Registers Agency.

The results indicate that the mining and quarrying sector achieves the highest overall performance, demonstrating superior financial efficiency and profitability compared to other major export-oriented sectors. At the other end of the spectrum, the sector of professional, scientific, and technical activities is ranked in the last position. Among the evaluated indicators, the

accounts receivable turnover ratio was identified as the most influential, emphasizing the critical role of operational efficiency in shaping overall sector performance. Sensitivity analysis further confirmed the consistency and robustness of the rankings across both weighting scenarios.

Given these results, several policy implications can be drawn. The strong profitability of the mining sector presents a strategic opportunity for the Serbian government to incentivize investments in sustainable practices and green mining technologies, which would help mitigate the environmental impact of mining activities and support the country's transition toward a low-carbon economy. One potential measure could be the partial exclusion of reinvested profits in green technologies from the corporate tax base, encouraging mining companies to allocate more resources toward environmental protection, energy efficiency, and cleaner production methods. In addition, targeted support for operational efficiency improvements, including better receivables management and process optimization, could further strengthen the competitiveness of the sector

while ensuring long-term economic and environmental sustainability.

While the findings offer valuable insights, certain limitations should be acknowledged. The analysis relies on aggregated sector-level data, which may overlook variations among individual entities within the mining and quarrying sector. Additionally, the focus on financial indicators excludes other important dimensions such as innovation capacity, environmental impact, and workforce productivity, which could provide a more comprehensive evaluation of sectoral performance. The study also considers data from selected years only, limiting the understanding of performance dynamics over time.

Future research could address these limitations by collecting and analyzing data at the firm or sub-sector level to capture intra-sectoral differences, and by incorporating non-financial and sustainability-related criteria for a multidimensional assessment of performance. Expanding the dataset to include multiple years would enhance understanding of sectoral trends and dynamics between periods. These extensions would provide a more nuanced and reliable understanding of the relative position of the mining and quarrying sector within the broader Serbian economic structure.

Acknowledgement

The research presented in this paper was carried out with the financial support of the Ministry of Science, Technological Development and Innovation of the Republic of Serbia within the framework of financing scientific research work at the University of Belgrade. Technical Faculty in Bor. in accordance with the contract with registration number 451-03-34/2026-03/200131.

Note

A part of this study was presented at the 56th International October Conference on Mining and Metallurgy, organized as a joint effort of Technical faculty in Bor of the University of Belgrade and Mining and metallurgy institute in Bor, from 22 - 25 October 2025, Bor Lake, Bor, Serbia.

7. References

- [1] Mudd, G. M. (2021) Assessing the availability of global metals and minerals for the sustainable century: from aluminium to zirconium. Sustainability, 13(19), 10855. <https://doi.org/10.3390/su131910855>

- [2] Fortier, S. M., Thomas, C. L., McCullough, E. A., Tolcin, A. C. (2018) Global trends in mineral commodities for advanced technologies. *Natural Resources Research*, 27(2), 191-200. <https://doi.org/10.1007/s11053-017-9340-9>
- [3] Ignjatović, M., Miletić, S. (2018) Evaluation of the sustainable development benefits in the Serbian mining companies. *Mining and Metallurgy Engineering Bor*, (3-4), 87-96. <https://doi.org/10.5937/mmeb18040871>
- [4] Filipović, S., Orlov, A., Panić, A. A. (2024) Key forecasts and prospects for green transition in the region of Central Asia beyond 2022. *Energy, Sustainability and Society*, 14(1), 25. <https://doi.org/10.1186/s13705-024-00457-0>
- [5] Serbian Business Registers Agency (2016) Financial Statements Annual Bulletin for 2015, Available at: <https://www.apr.gov.rs/upload/Portals/0/GFI%202015/Bilten%202016.pdf>
- [6] Serbian Business Registers Agency (2025) Financial Statements Annual Bulletin for 2024, Available at: https://www.apr.gov.rs/upload/Portals/0/GFI_2025/Bilten2025.pdf
- [7] Zielińska-Chmielewska, A., Kaźmierczyk, J., Jaźwiński, I. (2021) Quantitative research on profitability measures in the polish meat and poultry industries. *Agronomy*, 12(1), 92. <https://doi.org/10.3390/agronomy12010092>
- [8] IEA (International Energy Agency) <https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b9eed19457335/GlobalEnergyReview2021.pdf> Accessed 03/2026
- [9] European Commission, (2023) Critical Raw Materials Act: Securing sustainable supply chains for Europe's green and digital future, Brussels: EC Publications https://single-market-economy.ec.europa.eu/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en Accessed 03/2026
- [10] Stevović, I., Țîrcă, D. M., Hadrović, S. (2024) Mining management strategy towards circular economy and sustainable development. In: *Mining and Geology Today III International Symposium*. Mining Institute Ltd Belgrade, Serbia, Proceedings, 349-362. <http://dx.doi.org/10.5937/RGD240035S>

- [11] McMahon, G., Moreira, S. (2014) The contribution of the mining sector to socioeconomic and human development. *Extractive industries for development series*, 30.
<https://openknowledge.worldbank.org/handle/10986/18660>
- [12] Owen, J. R., Kemp, D. (2013) Social licence and mining: A critical perspective. *Resources policy*, 38(1), 29-35.
<https://doi.org/10.1016/j.resourpol.2012.06.016>
- [13] Dare, M., Schirmer, J., Vancly, F. (2014) Community engagement and social licence to operate. *Impact assessment and project appraisal*, 32(3), 188-197.
<https://doi.org/10.1080/14615517.2014.927108>
- [14] Čavlin, M., Tankosić, J. V., Mirković, Z. (2022) Analysis of factors of financial and profit position as a method of integrated risk management in the mining sector. *Ekonomija-teorija i praksa*, 15(3).
<https://doi.org/10.5937/etp2203056c>
- [15] Kržanović, D., Ljubojev, M., Jovanović, I., Vušović, N. (2017) An analysis the effects of changes in price of metal and operating costs to the profit in exploitation the copper ore deposits, a case study: Copper mine Majdanpek, Serbia. *Mining and Metallurgy Engineering Bor*, (3-4), 51-58.
<https://doi.org/10.5937/mmeb1704051K>
- [16] Komasi, H., Yazdi, A. K., Ozaydin, G., González, G. V., Jamini, D. (2026) Evaluation and Ranking of Iran's Provinces in Terms of Mining Development Using Multicriteria Decision-Making (MCDM) Techniques. *Complexity*, 2026(1), 4594108.
<https://doi.org/10.1155/cplx/4594108>
- [17] Rahimdel, M. J., Noferesti, H. (2020) Investment preferences of Iran's mineral extraction sector with a focus on the productivity of the energy consumption, water and labor force. *Resources Policy*, 67, 101695.
<https://doi.org/10.1016/j.resourpol.2020.101695>
- [18] Sobczyk, E. J., Kicki, J., Sobczyk, W., Szuwarzyński, M. (2017) Support of mining investment choice decisions with the use of multi-criteria method. *Resources Policy*, 51, 94-99.
<https://doi.org/10.1016/j.resourpol.2016.11.012>
- [19] Shahabi, R. S., Basiri, M. H., Qarahasanlou, A. N., Mottahedi, A., Dehghani, F. (2022) Fuzzy MADM-based model for prioritization of investment risk in Iran's mining projects. *International Journal of Fuzzy Systems*, 24(7), 3189-3207.
<https://doi.org/10.1007/s40815-022-01331-x>
- [20] Stuehlen, C., Anderl, F. (2024) Transnational companies in environmental conflicts: Rio Tinto, anti-mining resistance in Serbia, and the contradictions of Europeanization. *Zeitschrift für Friedens-und Konfliktforschung*, 13(1), 243-268.
<https://doi.org/10.1007/s42597-024-00114-5>
- [21] Živković, Ž., Panić, M., Fedajev, A., Veličković, M. (2023) The Challenges of Increasing the Copper Smelter Capacity on Ambient Air Quality in Bor (Serbia). *Water, Air, & Soil Pollution*, 234(2), 82.
<https://doi.org/10.1007/s11270-023-06090-5>
- [22] Sydd, O., Sairinen, R., Orenius, O., Tiainen, H. (2022) Social impacts of modern small-scale mining: case studies from Serbia and Bosnia & Herzegovina. *Society & Natural Resources*, 35(8), 816-835.
<https://doi.org/10.1080/08941920.2022.2079157>
- [23] Stepanović, I. (2025) From patriotism to transnationalism: Exploring hashtag narratives on lithium mining protests in Serbia. *Nationalities Papers*, 53(4), 755-776.
<https://doi.org/10.1017/nps.2024.48>
- [24] Fedajev, A., Voza, D., Panić, M., Veličković, M. (2022) Economic challenges of entrepreneurs in the Republic of Serbia operating in the most prospective economic activities operations by economic sectors in the Republic of Serbia in 2018. *The Annals of the Faculty of Economics in Subotica*, 58(47), 49-64.
<https://doi.org/10.5937/AnEkSub2247049F>
- [25] Fedajev, A., Miličević, R., Cvetković, M., Cogoljević, V. (2021) Business operations of entrepreneurial stores in the field of agriculture in the Republic of Serbia in the period 2015-2019. *Economics of Agriculture*, 68(2), 547-563.
<https://doi.org/10.5937/ekoPolj2102547F>
- [26] Krstić, S., Fedajev, A. (2020) The role and importance of large companies in the economy of the Republic of Serbia. *Serbian Journal of Management*, 15(2), 335-352.
<https://doi.org/10.3390/pr9081374>
- [27] Fedajev, A., Arsić, S. (2025) Is mining and quarrying most efficient and profitable export sector in Serbia? Insights from a multi-criteria performance analysis. In: *56th International October Conference on Mining and Metallurgy, Bor Lake, Serbia, Proceedings*, 695-699.
<https://doi.org/10.5937/IOC25695F>
- [28] Zavadskas, E. K., Turskis, Z., Kildienė, S. (2014) State of art surveys of overviews on MCDM/MADM

- methods. Technological and economic development of economy, 20(1), 165-179.
<https://doi.org/10.3846/20294913.2014.892037>
- [29] Kaya, A., Pamucar, D., Gürler, H. E., Ozcalici, M. (2024) Determining the financial performance of the firms in the Borsa Istanbul sustainability index: integrating multi criteria decision making methods with simulation. Financial Innovation, 10(1), 21.
<https://doi.org/10.1186/s40854-023-00512-3>
- [30] Liew, K. F., Lam, W. S., Lam, W. H. (2022) Financial network analysis on the performance of companies using integrated entropy–DEMATEL–TOPSIS model. Entropy, 24(8), 1056.
<https://doi.org/10.3390/e24081056>
- [31] Ghorabae, M. K., Zavadskas, E. K., Turskis, Z., Antucheviciene, J. (2016) A new combinative distance-based assessment (CODAS) method for multi-criteria decision-making. Economic Computation and Economic Cybernetics Studies and Research, 50(3), 25-44.
 Available at:
<https://etalpykla.vilniustech.lt/handle/123456789/116529>
- [32] Biswas, S., Pamučar, D. S. (2021) Combinative distance based assessment (CODAS) framework using logarithmic normalization for multi-criteria decision making. Serbian Journal of Management, 16(2). <https://doi.org/10.5937/sjm16-27758>
- [33] Kumari, A., Acherjee, B. (2022) Selection of non-conventional machining process using CRITIC-CODAS method. Materials Today: Proceedings, 56, 66-71.
<https://doi.org/10.1016/j.matpr.2021.12.152>
- [34] Goswami, S. S., Tapankumar, T., Naik, N. C. K., Gowrishankar, J., Bhosle, N., Singh, A., Raju, G. S., Nagesh, D. Santhosh, A. J. (2025) Multi-model MCDM framework for sustainable renewable energy selection in India: integrating CRITIC-EDAS-CODAS-CoCoSo. Discover Sustainability, 6(1), 500.
<https://doi.org/10.1007/s43621-025-01069-0>
- [35] Kannan, J., Jayakumar, V., Pethaperumal, M. (2025) Advanced fuzzy-based decision-making: the linear diophantine fuzzy CODAS method for logistic specialist selection. Spectrum of operational research, 2(1), 41-60.
<https://doi.org/10.31181/sor2120259>
- [36] Lukić, R. (2025) Analysis of climate change performance of G7 countries based on AHP-CODAS methods. The holistic approach to environment, 15(2), 47-56.
<https://doi.org/10.33765/thate.15.2.1>
- [37] Ning, B., Lei, F., Wei, G. (2022) CODAS Method for Multi-Attribute Decision-Making Based on Some Novel Distance and Entropy Measures Under Probabilistic Dual Hesitant Fuzzy Sets: B. Ning et al. International Journal of Fuzzy Systems, 24(8), 3626-3649.
<https://doi.org/10.1007/s40815-022-01350-8>
- [38] Pamucar, D., Badi, I., Sanja, K., Obradovic, R. (2018) A novel approach for the selection of power-generation technology using a linguistic neutrosophic CODAS method: A case study in Libya. Infinite Study. Energies, 11(9), 2489.
<https://doi.org/10.3390/en11092489>
- [39] Wei, C., Wu, J., Guo, Y., Wei, G. (2021) Green supplier selection based on CODAS method in probabilistic uncertain linguistic environment. Technological and Economic Development of Economy, 27(3), 530-549.
<https://doi.org/10.3846/tede.2021.14078>
- [40] Keshavarz-Ghorabae, M., Amiri, M., Zavadskas, E. K., Turskis, Z., Antucheviciene, J. (2021) Determination of objective weights using a new method based on the removal effects of criteria (MEREC). Symmetry, 13(4), 525.
<https://doi.org/10.3390/sym13040525>
- [41] Więckowski, J., Hernes, M., Sałabun, W. (2025) Comparison of multi-criteria decision analysis methods under comprehensive sensitivity analysis. IEEE Access, 13, 128122-128138.
<https://doi.org/10.1109/ACCESS.2025.3588166>

KOLIKO JE EFIKASAN I PROFITABILAN SEKTOR RUDARSTVA I EKSPLOATACIJE KAMENA U POREĐENJU SA VODEĆIM IZVOZNIH SEKTORIMA SRBIJE U 2024. GODINI? DOKAZI ZASNOVANI NA CODAS METODI

A. Fedajev^{1#}, S. Arsić¹, I. Božić Miljković¹

¹Univerzitet u Beogradu, Tehnički fakultet u Boru, Bor, Srbija

Primljen: 20. aprila 2026.; Prihvaćen: 3. avgusta 2026.

Izvod

Ovaj rad analizira efikasnost i profitabilnost sektora rudarstva i eksploatacije kamena (Sektor B prema NACE klasifikaciji) u poređenju sa ostalim vodećim izvozno orijentisanim sektorima u Srbiji u 2024. godini, primenom višekriterijumskog modela odlučivanja (MCDM) zasnovanog na CODAS metodi. Objektivne težine kriterijuma, određene primenom entropijske metode, pokazuju da najveći značaj ima koeficijent obrta kupaca (0,159), što ukazuje na najveće razlike među posmatranim sektorima, dok koeficijent obrta osnovnih sredstava ima najmanju težinu (0,108), ukazujući na najmanju međusektorsku varijabilnost. Rezultati pokazuju da je sektor rudarstva i eksploatacije kamena rangiran kao najefikasniji i najprofitabilniji sektor, dok sektor stručnih, naučnih i tehničkih delatnosti zauzima poslednje mesto. Analiza osetljivosti potvrđuje stabilnost i robusnost dobijenih rangova u različitim scenarijima određivanja težina i primenjenih metoda. Dobijeni rezultati predstavljaju značajnu osnovu za procenu konkurentnosti sektora i donošenje strateških, razvojnih, investicionih i javnih politika. Istovremeno, rezultati ukazuju da visoka profitabilnost rudarskog sektora stvara prostor za definisanje mera koje bi podstakle reinvestiranje dobiti u zelene tehnologije i primenu ekološki održivih rudarskih praksi.

Ključne reči: sektor rudarstva i eksploatacije kamena, profitabilnost, efikasnost, metoda entropije, CODAS metoda.