RGNZ/MGPB

A Global Sustainable Perspective on Surface Coal Mining Technology - Analytical Insight from Kosovo's Context

Rudarsko-geološko-naftni zbornik
(The Mining-Geology-Petroleum Engineering Bulletin)
UDC: 622.2
DOI: 10.17794/rgn.2024.3.4

Preliminary communication

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Abstract
Surface Coal Exploitation (SCE) predominantly relies on both continuous and discontinuous technologies, notably the bucket wheel and the truck and shovel methods. Specifically, the bucket wheel (continuous) method is optimal for expansive mines with favourable geological conditions, whereas the truck and shovel (discontinuous) method is better suited for mines with intricate geology, including smaller-scale operations. On a global scale, surface coal mining practices in Europe diverge somewhat from those in Australia and the USA. While shovel and truck configurations predominate in Australia and the USA, European nations predominantly employ bucket wheel excavators. Kosovo also boasts a rich heritage and proficiency in employing continuous technologies. This study elucidates the variations in coal production costs across different countries utilizing distinct technologies under diverse geological conditions, thereby enabling an insightful analysis of individual mine performance. The cost of coal production ($/t), accompanied by respective stripping ratios (SR), stands at 18.7 (SR, 3:1) in Kosovo, 13.8 (SR, 1.3:1) in the USA, and 7.37 (SR, 4:1) in Germany. The research underscores that the cost and productivity of surface coal production are contingent upon the alignment of technology with the geological and geometrical attributes of the mine. The comparative methodology, augmented by a comprehensive literature review and in-situ analysis, forms the backbone of this research. Concurrently, Excel-Pivot Chart analysis, in conjunction with Matlab, serves as the computational engine for data processing and analysis.

Keywords:
surface mining; coal; production; cost; technology

1. Introduction

Throughout history, coal has played a pivotal role in driving industrial development on a global scale, facilitating advancements such as the proliferation of the steam engine, steel production, and electricity generation, among others. Coal is found in huge amounts worldwide and is expected to play a crucial role as an abundant energy source. Coal mining and coal-fired power generation combined generated approximately $13.9 billion in total economic activity in the state of West Virginia in 2019, supporting nearly 33.3 thousand jobs, providing around $2.8 billion in employee compensation, supporting more than $611 million in severance tax and select state and local tax revenue for West Virginia and its local government (**Christiadi, 2021**). However, one critical issue in promoting coal utilization is controlling environmental pollution. Clean coal technologies are needed to utilize coal in an environmentally acceptable way and to improve coal utilization efficiency (**Chen and Xu, 2010**). In this regard, the European Union has supported research in clean-coal technologies and Carbon Capture and Storage (CCS) through its Framework Programmes (177), with over 117 million euro expended in financing over 40 projects since 1998, a large amount of investments in such research have also been made in other countries such as the US, Japan and China (**Chikkatur et al., 2011**). Coking coal has been on the European list of critical raw materials since 2014 due to its high economic importance and high supply risk (**Duda and Valverde, 2021**). Indeed, research focusing on technological innovation for sustainable coal utilization remains paramount in the years ahead. This imperative underscores the need to address environmental concerns while maximizing the efficient and responsible utilization of coal resources. The ongoing efforts in this area aim to make significant contributions towards achieving a balance between energy security, economic development, and environmental stewardship. Certainly, the issues addressed in this research align with the broader mission of advancing technological innovation for sustainable coal utilization. By tackling environmental concerns, promoting efficiency, and advocating responsible resource management, this research contributes to the overarching goal of achieving a harmonious

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balance between energy security, economic prosperity, and environmental stewardship.

The pace of technological advancement in coal extraction from open-pit mines is influenced by the imperative of boosting productivity and reducing costs. However, the extent of this progress is contingent upon various factors, including the geometric layout of the mine and the geological characteristics of the coal deposits, as emphasized by **Liu G., et.al., (2023)**. The optimization of technology for hourly utilization in Kosovo's coal mines constitutes a primary focus of this research endeavor. This investigation aims to enhance efficiency through the meticulous examination of various factors, such as equipment deployment, mine structural geometry, geological conditions, and the costs associated with overburden removal, among others. Nes'e Çelebi stressed, in surface mining, overburden removal represents the most critical aspect in terms of cost. Consequently, the incentive to limit and reduce costs in this area remains high. In regards to the determination of the hourly cost, besides the equipment type and size, operating conditions are also taken into account as being effective (**Çelebi, 1998**).

1.1. Geological conditions of the "Kosovo coal basin"

The inception of coal exploration in Kosovo dates back to the early XX century, marked by the recognition of extensive coal reserves within its territory. The initial subterranean exploitation of the Hade and Babush (Lipjan) mines commenced in 1922. The systematic investigation of the Kosovo coal basin ensued between 1952 and 1957. This period witnessed preparatory endeavours aimed at economically harnessing the coal resources within the Kosovo basin. The transition from subterranean mining to expansive open-cast mining was deliberated, with a strategic focus on the potential for widespread utilization of the available resources for coal-based thermal power plants and industrial coal processing applications (**Lanke et al., 2016**). Coal, primarily lignite, epitomizes Kosovo's paramount energy asset, boasting approximately 12.50 billion tons of reserves. This resource accounts for roughly 97% of the total electricity production. Key coal basins in Kosovo include the Kosovo Basin, the Dukagjini Basin, and the Drenica Basin (see **Figure 1**) (**Zeqiri and Peci, 2022**).

As a matter of coal exploitation, it is conducted in the Kosovo basin (see **Figure 1**). Its resources are estimated to be more than 10 billion tons of lignite coal. The lignite deposit under consideration is dated to the upper Miocene period, approximately nine million years old. It possesses an average calorific value of 7800 kJ/kg, with ash content typically falling within the range of 14-17%, and moisture content varying from 42% to 49% (**RWE, 2007**). Notably, coal extraction from this basin has been pivotal in sustaining national electricity generation since 1960.

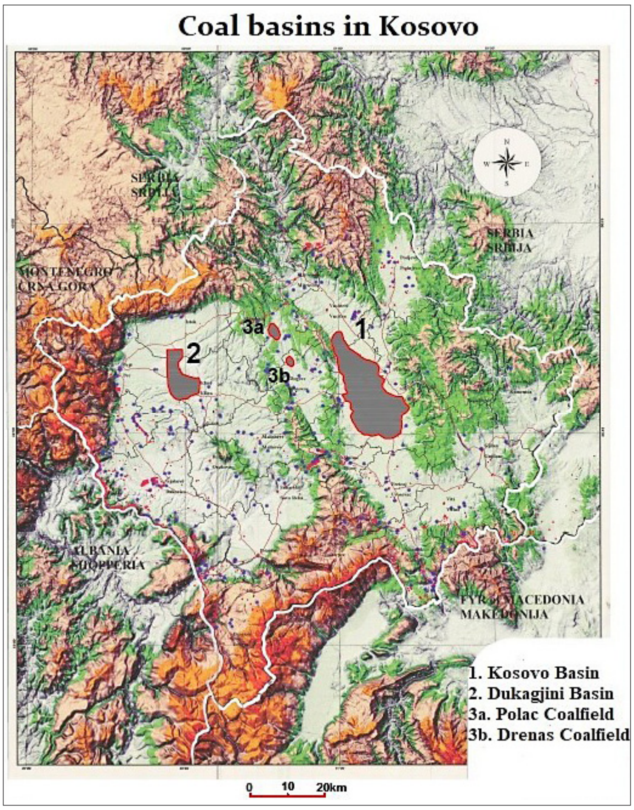

Figure 1: Coal basins in Kosovo

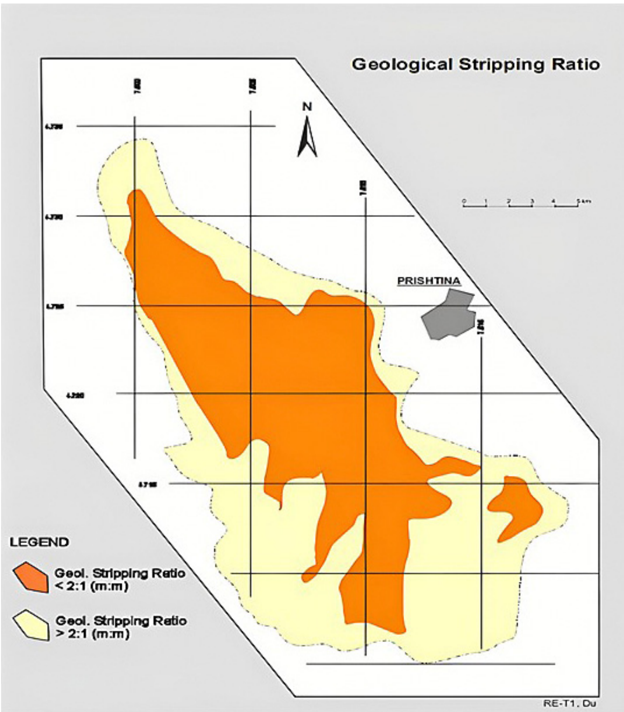

Figure 2: Kosovo lignite basin - geological stripping ratio (**RWE, 2007**)

Within the active mining region, known as the Kosovo coal basin (see **Figure 1**), the thickness of the coal seam fluctuates between 56 and 70 meters. The original overlying strata exhibit thicknesses ranging from 60 to

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120 meters, while the eastern portion presents a significantly reduced overburden depth of approximately 10 meters. The overburden composition predominantly comprises silt and clay formations, interspersed with sandy layers that serve as aquifers (**RWE, 2007**).

Compared to similar lignite deposits in other coal basins, the Kosovo basin offers distinct economic and mining advantages. This is primarily attributable to the relatively lower volume of overburden, estimated at approximately 15,857,000,000 cubic meters within the geological boundary. Consequently, the stripping ratio remains favourable at 1.76 cubic meters per cubic meter (**Lanke et al., 2016**). **Figure 2** illustrates the geological stripping ratio, which registers at less than 2:1.

Based on the study "Lignite resource allocation" conducted in 2006 year by RWE, the mining cost per ton of lignite is between €7.8 - €11/ton.

2. A review of existing mining methods

Surface mining methods constitute the predominant means of mineral extraction globally, encompassing over 80% of metallic/non-metallic mineral production and 50% of coal production. Approximately 80% of all materials processed within the mining sector are handled through surface methods. Given the current landscape, surface mining is poised to remain the primary avenue for sourcing most mining commodities in the foreseeable future (**Ramani, 2011**). In mining endeavours where ore production stands as the paramount objective, a profound understanding of operational dynamics proves indispensable for risk management, cost optimization, and output enhancement (**Lanke et al., 2016**). Surface Coal Exploitation (SCE) primarily revolves around persistent and discontinued exploitation technologies, commonly referred to as mining methods, notably truck shovel and bucket wheel methods. The coal production operations in Kosovo boast a rich tradition and extensive experience in employing continuous technology, specifically bucket wheel excavators, complemented by conveyor belt systems as depicted (see **Figure 3**).

In Europe, particularly in countries such as Germany, the Czech Republic, and Poland, surface or open pit mining employs technology that diverges somewhat from practices observed in Australia and the USA. While draglines or shovel and truck configurations are prevalent in Australia and the USA, bucket wheel excavators and remote band conveyors constitute the primary equipment for mining and overburden transportation in Europe, specifically in the Czech Republic and Germany (**Hummel, 2012**).

The machinery predominantly utilized for overburden removal comprises draglines, dredgers, dozers, and truck and shovel operations. These methods can also be adapted for coal exploitation, except for the use of draglines. Overburden removal holds significant importance in surface mining operations, often accounting for up to half of the total expenses incurred in coal exposure, extraction, washing, and transportation (**Scott et al., 2010**).

Mitra. R, et al. underscore the prevalence of draglines in Australian coal exploitation, particularly when the deposit's characteristics align with the physical capabilities of dragline equipment. Draglines are renowned for their cost-effectiveness in overburden removal, often referred to as the "Dragline Method" (**Rudrajit and Serkan, 2012**). Dragline excavators are distinguished by their low operational costs juxtaposed with high capital investments.

Presently, draglines and truck and shovel operations, or a combination thereof, constitute the predominant equipment utilized in open-cut mines (see **Figure 4**).

The truck and shovel mining method emerges as the most adaptable technique, rendering it particularly suit-

Figure 3: Overview of mine, a) mine pit-cast mining and b) conveyor belt

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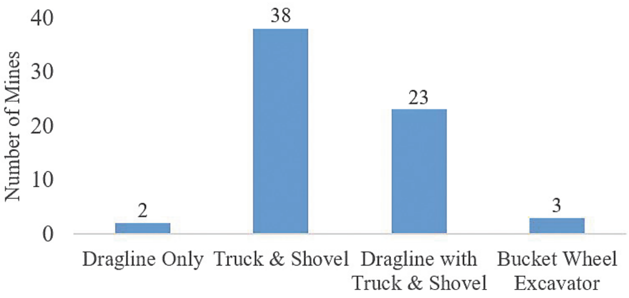

Figure 4: Open cut mining technology used in Australia (**Scott et al., 2010**)

able for geologically intricate deposits, variable overburden depths and thicknesses, as well as smaller deposits (**Rudrajit and Serkan, 2012**).

Another method employed for overburden removal in open-cut coal mines involves the deployment of bucket wheel excavators or dredgers. While bucket wheel excavators also serve for coal extraction, their utilization is not as widespread. However, it is important to note that bucket wheel excavators represent an expensive and ageing technology, which is not extensively adopted in the contemporary mining industry (**Scott et al., 2010**).

3. Methods

The methodology likely includes a comprehensive review of existing literature on surface coal mining technologies, cost analysis, and productivity rates. This step helps establish the context for the research and identifies gaps or areas for further investigation.

The researchers likely collected data on surface coal mining practices, costs, and productivity rates from various sources. This data includes information on the type of technology used (e.g. bucket wheel vs. truck and shovel), geological characteristics of the mines, and production costs (overburden removal and coal exploitation).

The methodology involves a comparative analysis of surface coal mining practices across different countries, with a focus on Europe, Australia, and the USA. This analysis aims to identify variations in production costs and productivity rates associated with different technologies and geological conditions.

The study entails an analysis of the Coal Production Report spanning the years 2019 to 2021, coupled with on-site observational research conducted at Kosovo's coal mine. This methodological approach encompasses direct engagement with mining operations, geological examinations, and the evaluation of technological applications. Through in-situ observations, comprehensive first-hand insight is garnered, enriching the investigation with empirical data and contextual understanding.

The methodology includes data processing and analysis using computational tools such as Excel-Pivot Chart and Matlab. These tools likely help organize and analyse the collected data, allowing for a quantitative assessment of cost-effectiveness and productivity across different mining technologies employed in surface coal mining.

The research methodological framework consists of assessing the relationship between surface coal production costs, productivity rates, and technological approaches and utilisation. This methodology has served as a comprehensive approach for conducting the research and interpreting the findings.

The overall methodology of the paper consists of theoretical insight from a literature review with empirical data collection and analysis to investigate the relationship between surface coal mining technologies, geological conditions, production costs, and productivity rate.

4. Results

4.1 Truck and Shovel vs Bucket Wheel in a cost context

In the West Virginia Mine situated in the upland platform Allegheny (USA), the truck and shovel technology, as highlighted by Hummel. T, incurs a cost of $1.4 per cubic meter of overburden for transportation over a distance of 518 meters.

Conversely, in the North Bohemia mines located in the Czech Republic, the bucket wheel technology operates for $4.92 per cubic meter for overburden production (**Hummel, 2012**).

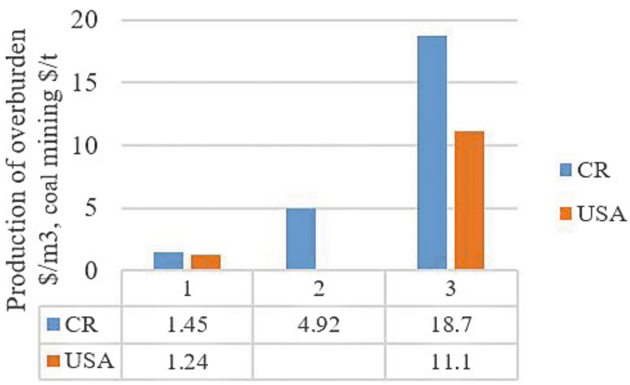

Figure 5: Comparison of coal mining costs in the USA and Czech Republic (CR). 1—production costs without handling by conveyor; 2—production costs with handling by conveyor; 3—total expenditure on coal mined.

The comparison of production costs per cubic meter of overburden and per ton of coal between bucket wheel and truck and shovel technologies is elucidated (see **Figure 5**). The data reveals that the cost of producing one ton of coal in the Czech Republic is approximately 70% higher than in the USA.

4.2 Bucket Wheel performance – Coal Mining, Kosovo case

The analysis of Kosovo coal mining technology involves two key aspects:

(i) Cost production: this aspect scrutinizes the expenses incurred throughout the coal mining process, encompassing equipment, labour, maintenance, and other operational overheads. Understanding the cost production dynamics allows for effective budgeting, cost optimization, and overall financial management within the mining operations.

(ii) Excavator performance: the evaluation of excavator performance comprises both theoretical and effective assessments. The theoretical performance delineates the anticipated capabilities and efficiencies of the excavators based on design specifications and operational parameters. On the other hand, effective performance encompasses the real-world outcomes and operational efficiencies observed during mining activities. Analysing both theoretical and effective excavator performance provides insight into operational effectiveness, productivity levels, and areas for potential improvement within the mining operations in Kosovo.

4.2.1. Coal cost production (CCP)

According to the RWE report in 2007, the average cost of coal production stands at approximately €10 per ton. However, it's important to note that the mineral rent, which was about €0.30 per ton at that time, increased to €3 per ton by 2010. Consequently, this escalates the overall cost to approximately €13 per ton, as indicated by mine representatives.

In Germany, the average cost of lignite production over the latest available five-year period is reported to be €6.91 per megawatt-hour (MWh) of lignite. This figure encompasses the comprehensive expenses associated with lignite mining and assumes a heating value of 2.51 MWh per ton of raw lignite (**Fernahl et al., 2015**).

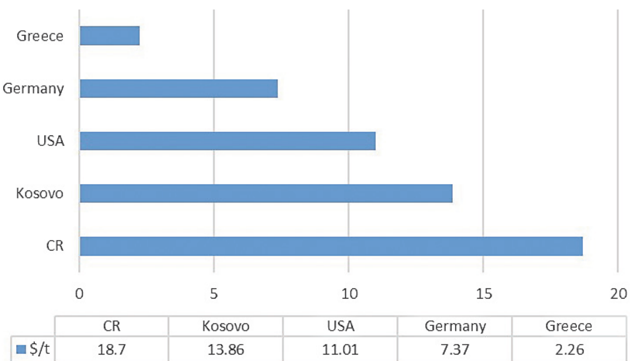

Figure 6: A comparison of coal production in some countries, based on cost per ton

Furthermore, based on a study commissioned by the Greek Public Power Corporation (PPC) to Booz & Co Consultants, the cost of lignite extraction in Greece is reported to be €2.12 per ton, which is notably lower and comparable to the cost in Germany (**URL1, 2016**).

Figure 6 illustrates the disparity in coal production costs across various countries. However, it is imperative to recognize that the methodology employed for cost estimation, such as Germany's reliance on heat value, and geological factors like the stripping ratio, significantly influence the accuracy and applicability of this comparison.

The stripping ratio (SR) emerges as a pivotal parameter in surface coal mining cost analysis. An examination of the average stripping ratios across the countries under study reveals distinctive trends: coal mines in the Czech Republic maintain a stripping ratio of 3:1 (**Hummel, 2012**), while those in Germany exhibit a higher stripping ratio of 4:1 (**URL2, 2000**). In contrast, coal mines in the USA operate with a stripping ratio exceeding 5:1 (**Aul Averit, 1968**).

Significantly, the coal mines in Kosovo boast an average stripping ratio of 1.3:1, a notably favourable condition compared to other regions. Coupled with other advantageous geological factors, the cost of coal exploitation in Kosovo's mines, when juxtaposed with those depicted (see **Figure 6**), appears inefficient. Consequently, it is plausible that the actual coal mining cost per ton in Kosovo might be 3 to 4 times lower than the figures presented.

4.2.2. Excavators performance in coal and overburden mine in Kosovo

Analysing the capacity of excavators within mining operations is of paramount importance for enhancing efficiency and productivity. By comprehending the capabilities of excavators, mining activities can be meticulously planned to ensure optimal utilization, minimizing wastage of operative time and maximizing output.

In mines where resources are both limited and costly, a thorough analysis of excavator capacity enables the

Table 1: Excavator's performance in South-West Sibovc coal mine, Kosovo

Excavators	Theoretical capacity (m^3/h)	Swelling coefficient of coal	Theoretical capacity of coal (t)	Load ratio	Effective capacity (t)	Nominal coal capacity (t/year)	
						Min nominal coal production (h/year) 4266 h	Max nominal coal production (h/year) 5474 h
SRs 1300.26 (E8M)	4200	1.7	2471	45%	1111.76	4742788.24	6085800
SRs 400 (E7M)	2200	1.7	1294	28.3%	366.24	1562359.76	2004772
SRs 470 (6B)	1690	1.7	994	30%	298.24	1272271.76	1632540
SRs 470 (3B)	1690	1.7	994	30%	298.24	1272271.76	1632540
SRs 470 (7B)	1690	1.7	994	30%	298.24	1272271.76	1632540

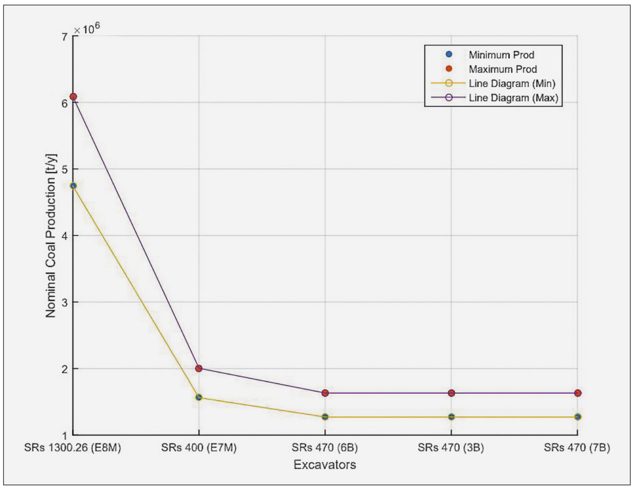

Figure 7: Nominal coal production (t/year)

and optimization efforts aimed at enhancing overall mining performance in the southwestern Sibovc coal mine.

As depicted in **Figure 7**, the analysis of reports indicates an annual operating time ranging from 4,266 to 5,474 hours per year for the five excavators included in this research. Consequently, the nominal coal capacity for these excavator's spans from 1,272,271.76 tons per year to 6,085,800 tons per year.

To analyze the data from the 2019, 2020, and 2021 reports, the MatLab program was employed. This software tool facilitates comprehensive examination and interpretation of excavator performance metrics, enabling detailed insight into operational trends, potential efficiency improvements, and strategic planning for enhancing overall productivity within the southwestern Sibovc coal mine.

Table 2: Excavator's performance - overburden

Excavators	Theoretical capacity (m^3/h)	Swelling coefficient of overburden	Theoretical capacity of overburden (t)	Load ratio	Effective capacity (t)	Nominal overburden capacity (t/year)	
						Min nominal overburden production (h/year) 4266 h	Max nominal overburden production (h/year) 5474 h
SchRs 650 (E9M)	4212	1.55	2717.42	29 %	788.05	3361828.18	4313794.53
SchRs 650 (E10M)	4212	1.55	2717.42	29 %	788.05	3361828.18	4313794.53
SRs 1300.24 (E8B)	4000	1.55	2580.65	24 %	619.35	2642167.74	3390348.39
SRs 1300.24 (E10B)	4000	1.55	2580.65	24 %	619.35	2642167.74	3390348.39
SRs 470 (E5M)	1690	1.55	1090.32	24 %	261.68	1116315.87	1432422.19

optimization of resource utilization. This optimization ensures that resources are deployed efficiently and productively, contributing to overall operational effectiveness and cost-effectiveness. Moreover, such optimization measures can have a positive impact on environmental protection, as they minimize resource consumption and reduce the environmental footprint of mining operations

The analysis of excavator productivity in the coal mine located in southwestern Sibovc was conducted to explore opportunities for enhancing the mine's productive capacity (see **Table 1**). Drawing from reports spanning 2019, 2020, and 2021, the research focused on eight active excavators within the mine during varying periods (**KEK, 2021**), (**KEK, 2022**). However, the analysis primarily centred on five excavators consistently active throughout the three-year timeframe.

By leveraging excavator capacity data, strategies can be formulated to bolster their efficiency and productivity within the mining operation. This analytical approach facilitates the identification of operational bottlenecks, areas for improvement, and opportunities for streamlining workflows to maximize output. Consequently, insight gleaned from excavator productivity analysis serves as a cornerstone for informed decision-making

Table 2 illustrates the capacity of the excavators. The analysis of these data is facilitated by the utilization of the Matlab software, culminating in the visualization of results depicted in **Figure 8**. Through Matlab, comprehensive examination and interpretation of excavator capacities are conducted, providing valuable insight into operational dynamics and performance metrics within the mining operation. **Figure 8** offers a graphical representation of the excavator capacity analysis, enabling stakeholders to make informed decisions and strategic adjustments aimed at optimizing productivity and efficiency in mining operations.

Based on the analysis of reports, the annual operating time for overburden excavators falls within the range of 4,266 to 5,474 hours per year (see **Figure 8**). Consequently, the nominal overburden capacity for the five excavators under scrutiny spans from 1,116,315.87 tons per year to 4,313,794.53 tons per year. This analysis provides critical insight into the potential capacity and performance of overburden excavators within the mining operation, aiding in strategic decision-making and operational planning to optimize overburden removal efficiency and productivity.

Based on the reports from 2019 to 2021, the average production was compared with the nominal production

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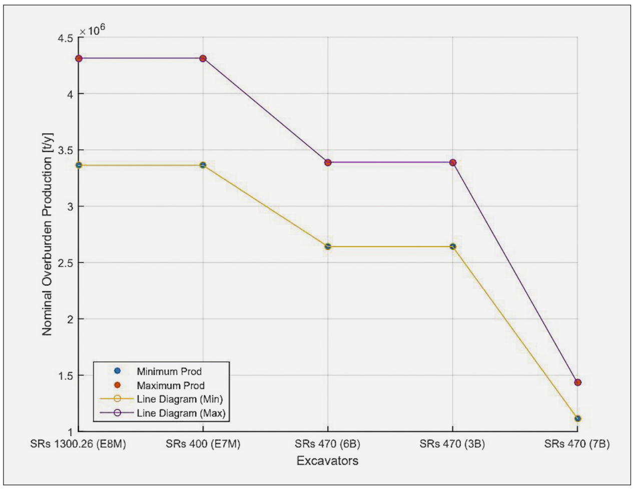

Figure 8: Nominal overburden production (t/year)

rates ranging from 53% to 68%. Excavator SRs 470 (7B) were observed to have the least utilization, achieving rates between 38% and 49%. These findings provide valuable insight into excavator performance and utilization trends, facilitating strategic adjustments and optimization efforts within the mining operation to enhance overall productivity and efficiency (see **Figure 9**).

From **Table 4**, it is evident that the average production from 2019 to 2021 compared to the nominal capacity varies across the active excavators in the overburden. The data suggests that the excavator SchRs 650 (E10M) exhibits the highest utilization, ranging between 70% and 90% in comparison to others. Conversely, other excavators demonstrate lower levels of utilization, averaging between 59% and 76%. Notably, the excavator SRs 470 (E5M) shows the lowest utilization, operating at only 22% to 28% of its nominal capacity.

Table 3: Excavator's performance - coal production

Excavators	Effective capacity t/h	Average production 2019 - 2021 (t/y)	Ratio/Min coal nominal production (%)	Ratio /Max coal nominal production (%)
SRs 1300.26 (E8M)	1111.76	3061112.00	65%	50%
SRs 400 (E7M)	366.24	1052867.00	67%	53%
SRs 470 (6B)	298.24	936041.67	74%	57%
SRs 470 (3B)	298.24	1277614.33	100%	78%
SRs 470 (7B)	298.24	619921.67	49%	38%

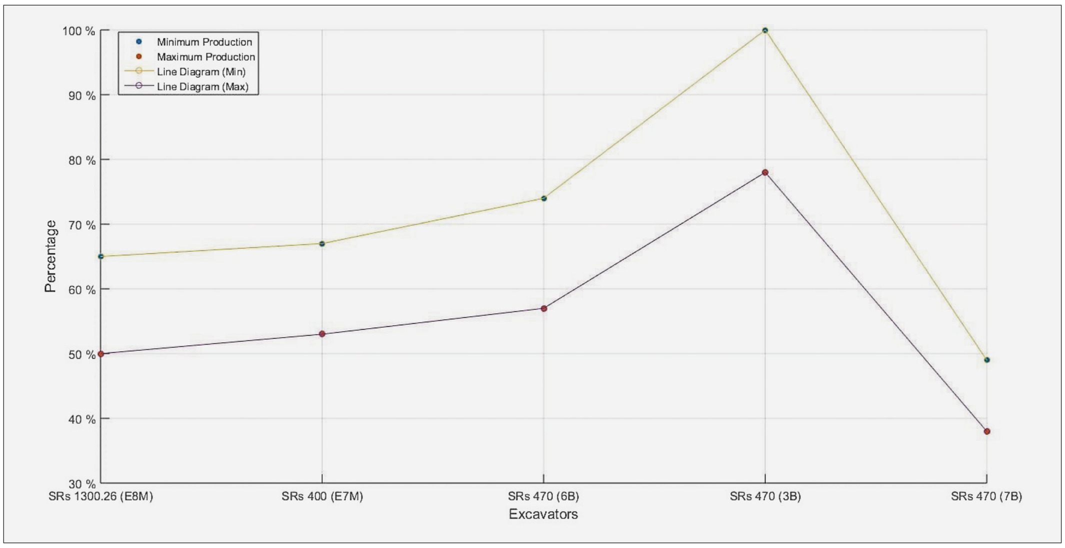

Figure 9: Ratio between average production 2019 – 2021 and min/max-nominal coal capacity

across various scenarios, as outlined in **Table 3**. Additionally, the utilization of excavators was examined under different ratios, as shown in **Table 4**. Notably, the excavator with SRs 470 (3B) exhibited the most effective utilization, achieving nominal production rates between 78% and 100%. Conversely, other excavators demonstrated varying levels of utilization, with average

These findings underscore the importance of analyzing excavator performance and utilization trends to identify areas for improvement and optimize productivity within the overburden excavation process. By addressing factors contributing to lower utilization rates, such as operational inefficiencies or equipment limitations, mining operations can strive to enhance overall

Table 4: Analysis of overburden production

Excavators	Effective capacity t/h	Average production 2019 - 2021 (t/y)	Ratio/Min overburden nominal production (%)	Ratio /Max overburden nominal production (%)
SchRs 650 (E9M)	788.05	2819542.33	84%	65%
SchRs 650 (E10M)	788.05	3028471.00	90%	70%
SRs 1300.24 (E8B)	619.35	1554833.00	59%	46%
SRs 1300.24 (E10B)	619.35	2283267.67	86%	67%
SRs 470 (E5M)	261.68	309236.00	28%	22%

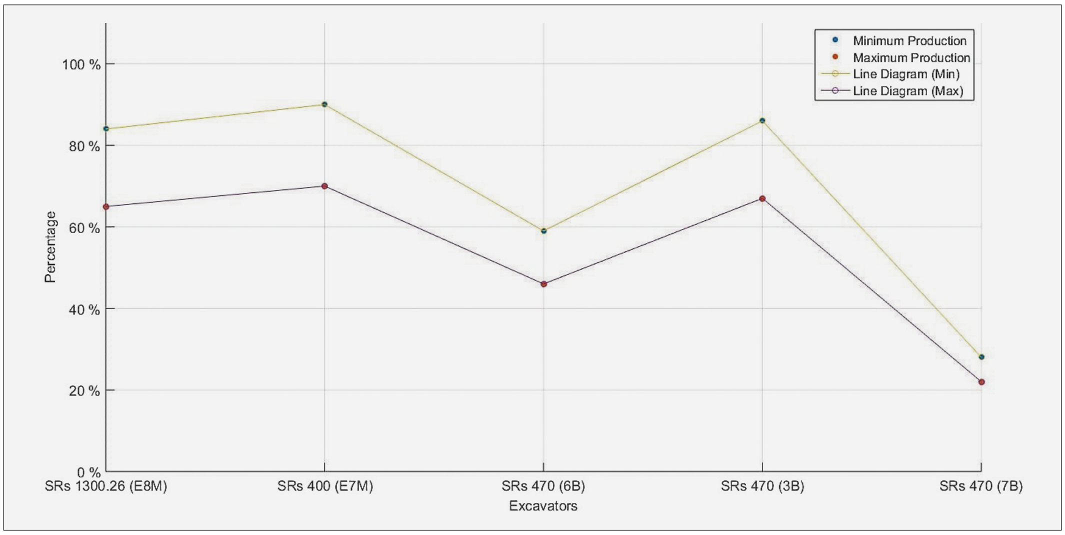

Figure 10: Ratio between average production 2019 – 2021 and min/max-nominal overburden capacity

performance and efficiency in overburden removal activities.

As is shown in **Figure 10**, overall, while some excavators perform near or above their nominal capacity, others exhibit underutilization and lower productivity. Addressing factors contributing to lower utilization rates and optimizing operational efficiencies could enhance overall performance and productivity within the overburden excavation process.

5. Conclusions

The truck and shovel technology, renowned for its lower capital investment and operational adaptability, finds particular suitability in mines grappling with intricate geological conditions. This approach is predominantly favoured in regions like the United States and Australia. This research delves into the competitive interplay between discontinuous technology, prevalent in these regions, and continuous technologies, predominantly embraced in Europe. The focus lies on factors such as production rates and unit production costs. In terms of cost-effectiveness, the one-ton coal production employing bucket wheel technology (Czech Republic) is observed to be 70% higher than in the United States. Bucket wheel technology, predominantly employed in Europe and categorized as a continuous method, typically involves a higher initial capital investment and may not be the optimal choice for mines facing complex geological challenges. Nevertheless, in extensive mines boasting favourable geological conditions, this technology showcases remarkable production rates, productivity levels, and cost efficiency compared to discontinuous technologies. Thus, when aligned with geological conditions and mine geometry, it can yield low production costs. For instance, in Germany's case, coal production costs amount to $7.37 per ton, compared to coal production in the Czech Republic, at $18.70 per ton.

Upon comprehensive analysis of Kosovo's implementation of bucket wheel technology, it becomes apparent that the excavator's capacity, both in terms of minimal and maximal operating times, remains underutilized. For instance, the average utilization performance of excavators employed in coal production stands at approximately 64%, while those engaged in overburden removal operate at around 57%. Optimizing excavator performance not only serves as a cost-saving measure but also holds significant implications for environmental conservation and sustainable mine development. However, a notable issue lies in the non-uniform utilization of excavators. For example, the SRs 470 (3B) excavator achieves an average utilization of approximately 89% in coal produc-

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tion, whereas the SRs 470 (7B) registers only 43%. Similarly, the excavator SchRs 650 (E10M) utilized in overburden removal maintains an average utilization of 80%, whereas the SRs 470 (E5M) excavators record a mere 25%. This inconsistency in excavator utilization not only leads to economic repercussions but also hampers the development of the mine's geometry, posing challenges in operational efficiency and productivity.

Regarding the technology employed in Kosovo coal mines, particularly the continuous bucket wheel method, despite favourable geological conditions and low stripping ratios, the observed low production rates and productivity metrics culminate in elevated production costs. This phenomenon may be attributed to various factors, including the limited mining area, insufficient maintenance practices, and reliance on outdated technology, thus necessitating urgent remedial measures for operational enhancement and cost efficiency.

Based on the research findings, it is advised that strategic management aligns the mine geometry with the current technology in use (bucket and wheel systems). Alternatively, consideration could be given to transitioning the operational technology towards more modern methodologies, such as the adoption of truck and shovel systems, or a hybrid approach combining both methodologies. This strategic adjustment shall enhance operational efficiency, optimize resource utilization, protect the environment, and promote sustainable mine development.

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SAŽETAK

Globalno održiva perspektiva površinske tehnologije eksploatacije ugljena – analitički uvidi iz kosovskoga konteksta

Površinska eksploatacija ugljena pretežno je bazirana na kontinuiranoj i diskontinuiranoj tehnologiji, posebice na metodama s rotornim bagerom i metodama s kombinacijom bagera lopatara i kamiona. Naime, metoda s rotornim bagerom (kontinuirana) optimalna je za velike rudnike s povoljnim geološkim uvjetima, dok je metoda s bagerom lopatarom i kamionom (diskontinuirana) prikladnija za rudnike sa složenom geologijom i u zahvatima manjega opsega. Na globalnoj razini praksa površinskoga dobivanja ugljena u Europi donekle se razlikuje od one u Australiji i SAD-u. Kombinacija bagera lopatara i kamiona prevladava u Australiji i SAD-u, a europske zemlje pretežno se koriste rotornim bagerima. Kosovo se također može pohvaliti bogatim nasljeđem i vještinom u korištenju kontinuiranih tehnologija. Ova studija podcrtava važne varijacije u troškovima proizvodnje ugljena u različitim zemljama koje se koriste različitim tehnologijama u različitim geološkim uvjetima, čime se omogućuje dubinska analiza učinka pojedinačnih rudnika. Troškovi proizvodnje ugljena, popraćeni odgovarajućim omjerima korisne površine (*Strip ratios* – SR), na Kosovu iznose 18,7 $/t (SR je 3 : 1), u SAD-u 13,8 $/t (SR je 1,3 : 1) i u Njemačkoj 7,37 $/t (SR je 4 : 1). Istraživanje naglašava da troškovi i produktivnost površinske proizvodnje ugljena ovise o usklađivanju tehnologije s geološkim i geometrijskim karakteristikama rudnika. Komparativna metodologija, proširena opsežnim pregledom literature i terenskom analizom, čini okosnicu ovoga istraživanja, dok istodobno Excel-Pivot Chart analiza u kombinaciji s Matlabom služi kao računalni mehanizam za obradu i analizu podataka.

Ključne riječi:
površinska eksploatacija, ugljen, proizvodnja, trošak, tehnologija

Author's contribution

Kemajl Zeqiri (1) (Prof. Dr.) and **Ujmir Uka (2)** (Asst. MSc.) provided analyses and interpretation of the data. **Risto Dambov (3)** (Prof. Dr.) provided interpretation of the data. **Burim Ferati (4)** (Bachelor of mining) collected data.