Management of Technical and Economic Factors in the Concept of Recovery, Production, and Processing of Hydrocarbons

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Abstract

This paper investigates the prospects for post-war revitalization of the Central Region of Donbas (CRD) through the establishment of an innovative technology park based on coal and hydrocarbon resource utilization, using the Toretska Mine of the State Enterprise Toretskugol as a case study. The study evaluates balance coal reserves within the mine field and analyzes existing and emerging technologies for the extraction and processing of hydrocarbon compounds. The Toretska Mine contains approximately 18.6 million tons of coal reserves, including 14.6 million tons of industrial reserves. With the current mining technology and an annual production capacity of 110 thousand tons, the estimated operational lifetime of the mine exceeds 130 years. In addition to conventional reserves, the deposit includes 20 coal seams with thicknesses ranging from 0.1 to 0.5 m, of which 11 seams have workable thicknesses of 0.25–0.5 m down to the −1500 m isogypsum level. The coal resources are primarily high-quality K and Zh grades, capable of yielding more than 350 valuable substances for industrial and agricultural applications. The paper highlights unconventional approaches to coal and methane extraction, including mining technologies for thin and very thin seams and methane recovery from depleted mine workings. Although stable profitability from thin-seam mining has not yet been demonstrated in practice, a comprehensive approach integrating advanced geotechnologies, hydrocarbon processing, and industrial symbiosis is proposed. Drawing on the experience of major energy enterprises, such as DTEK Energo, the creation of an innovative CRD technology park could enable additional value generation and contribute to sustainable regional recovery in the post-war period.

Keywords: *coal mining, thin coal seams, methane recovery, mining technologies, innovative solutions, technopark, livelihood restoration*

1. INTRODUCTION

The post-war reconstruction of Ukraine's economy presents a complex challenge that affects all sectors of industry and society, particularly regions located within or adjacent to former combat zones [1]. One of the most affected areas is the Central Region of Donbas (CRD), where the restoration of industrial capacity is closely linked to the recovery of the energy sector [1,2]. The reconstruction and development of new energy facilities are expected to rely on an increased share of solid fuels in the national energy balance, alongside the transition to advanced coal-based technologies, including fluidized bed and molten bath combustion, coal gasification, and pressurized coal combustion in combined-cycle power plants [1-3]. At the same time, the coal resources of the CRD are characterized by high-quality chemical properties and play a strategic role in Ukraine's metallurgical and chemical industries [4]. Consequently, the application of modern hydrocarbon processing technologies is becoming an essential prerequisite for sustainable economic development [2,4,5].

Ukraine's coal reserves are sufficient to ensure energy security for several centuries; however, their exploitation is associated with extremely challenging geological and mining conditions [3,6]. In the CRD, many industrial coal reserves are concentrated in thin seams with thicknesses ranging from 0.5 to 1.2 m, which are typically considered uneconomic or technically infeasible in many countries [2]. These seams are often characterized by high gas content and elevated risks related to coal dust explosions, while more than one-third are prone to sudden coal and gas outbursts and spontaneous combustion. Mining operations are conducted at depths of

800–1200 m, further complicating extraction and increasing operational costs and safety requirements [1,2].

In this context, the utilization of coal resources in the CRD can be conceptually compared with the processing of industrial and mining waste, which is increasingly viewed as a valuable secondary resource rather than an environmental burden [2,4,7,8]. Similar to waste utilization, the exploitation of thin and technically complex coal seams requires non-standard technological solutions, integrated processing chains, and a shift from primary extraction toward value-added conversion [9]. Both approaches align with the principles of a circular economy, where maximum value is derived from resources through advanced processing, co-production of energy and materials, and the reduction of environmental impacts [5,10]. This comparison highlights the need for systemic solutions that combine resource extraction, processing, and product manufacturing within a unified technological framework [3,6,11].

A persistent challenge in developing steeply dipping thin coal seams is the low level of mechanization, which in many cases corresponds to technological standards of the mid-20th century [12]. Although various unconventional mining methods have been tested at deep mines, research has shown that, despite their technical feasibility, they have not delivered sufficient efficiency gains or cost reductions compared to other coal basins [13]. Nevertheless, these studies have generated a substantial body of scientific and technical knowledge that remains largely underutilized in modern production processes. Contemporary economic development mechanisms and innovation-driven approaches create new opportunities to transform this accumulated knowledge into advanced technological solutions [5,6,9].

The innovative potential of such transformations is determined by the results of fundamental and applied research, while their practical implementation depends on the interaction between investors, industrial enterprises, scientific institutions, and creative teams [14]. The organizational structures formed through this interaction, technology parks, facilitate the accelerated transfer of research outcomes into industrial applications and commercial products [14,15]. In the global economy, technology parks have become a dynamically developing and widely adopted instrument for regional and industrial development, including in Ukraine [17]. The CRD is no exception to this trend; however, tangible and sustainable results can only be achieved when the full innovation chain, from scientific idea to market-ready products, aligned with societal and economic demand.

Despite the extensive body of research devoted to coal mining in the Donbas region, existing studies have predominantly focused on isolated technical, geological, or economic aspects of deep coal extraction [2]. Limited attention has been given to integrated frameworks that simultaneously address thin-seam mining challenges, advanced hydrocarbon processing, methane recovery, and post-war socio-economic recovery [18]. There is a lack of systematic analyses that consider coal deposits not only as primary energy sources but also as multifunctional raw materials within innovative-driven industrial ecosystems. Furthermore, the potential role of technology parks as platforms for combining unconventional mining technologies, waste and by-product utilization, and value-added production in post-conflict regions remains insufficiently explored [19]. This research addresses these gaps by proposing a comprehensive approach that links resource assessment, technological feasibility, and regional revitalization within the context of the Central Region of Donbas.

The purpose of this study is to analyze the current state of the coal industry in the Central Region of Donbas, with particular emphasis on coal reserves, geological and mining conditions of coal seam occurrences, and existing technologies for their development. Using the Separated Enterprise "Toretska Mine" of the State Enterprise Toretskvuhillia as a case study, the research aims to assess the feasibility of restoring industrial activity and improving population livelihoods through the application of innovative technological and organizational solutions.

2. Methods and Methodology of Technical and Economic Factors in the Concept of Recovery, Production, and Processing of Hydrocarbons

The research methodology is based on an integrated approach combining theoretical analysis, applied research, and elements of experimental verification. The study focuses on assessing technical, geological, and economic factors that determine the feasibility of restoring coal mining, methane extraction, and hydrocarbon processing in the Central Region of Donbas (CRD). The Separated Enterprise "Toretska Mine" of the State Enterprise Toretskvuhillia was selected as a representative case study due to its complex mining conditions, significant reserve base, and availability of long-term geological and operational data.

The theoretical component of the research involved a systematic analysis of scientific publications, regulatory documents, geological reports, and archival materials related to deep coal mining, thin-seam extraction, gas-dynamic phenomena, and hydrocarbon processing technologies [3,9,20]. Special attention was paid to studies addressing unconventional mining methods, underground coal gasification, hydrodynamic actions, methane recovery, and integrated resource utilization [21]. This literature analysis enabled the identification of technological limitations, economic constraints, and research gaps relevant to post-war recovery scenarios.

The empirical basis of the study relies on the analysis of geological, mining, and production data from the information database of coal seams developed at the mines of SE Toretskvuhillia [22]. This database includes parameters of coal seam thickness, dip angles, gas content, coal quality indicators, depth of occurrence, hazard classification, and hydrogeological conditions [23]. The collected data were used to evaluate the technical feasibility of extracting both balance and previously unaccounted reserves, including thin and very thin seams that were historically considered non-commercial.

The evaluation of technical feasibility for extracting balance and previously unaccounted coal reserves is based on a multi-parameter mathematical framework that integrates geological, mining, and production data. Each coal seam iis characterized by a vector of measurable parameters obtained from the mine database [20]:

$$X_i=\{h_i,\alpha_i,d_i,g_i,q_i,H_i,w_i\} \quad (1)$$

where:
h_i is the seam thickness (m);
α_i is the dip angle (°); d_i is the depth of occurrence (m);
g_i is the gas content (m^3/t);
q_i represents coal quality indicators (ash content, volatile matter, calorific value);
H_i is the hazard classification index (dimensionless);
w_i denotes hydrogeological conditions (water inflow rate or saturation index).

The extractable coal reserves R_i for seam i are determined as:

$$R_i = A_i \cdot h_i \cdot \rho \cdot \eta_i \tag{2}$$

where:
A_i is the area of the seam (m^2);
ρ is coal density (t/m^3);
η_i is the recovery coefficient, accounting for mining losses and technological constraints.

To assess the technical feasibility of seam development, a composite feasibility index F_i is introduced:

$$F_i = \sum_{k=1}^{n} w_k \cdot f_k(x_{ik}) \tag{3}$$

where:
x_{ik} are normalized parameters from vector X_i;
f_k (x_{ik}) are dimensionless normalization functions transforming heterogeneous parameters into a unified scale [0,1];
w_k are weighting coefficients reflecting the relative importance of each factor, satisfying:

$$\sum_{k=1}^{n} w_k = 1 \tag{4}$$

Each parameter is normalized according to its technological impact:

For limiting factors (e.g., gas content, depth):

$$f_k(x_{ik}) = 1 - \frac{x_{ik} - x_k^{\min}}{x_k^{\max} - x_k^{\min}} \tag{5}$$

For enabling factors (e.g., seam thickness, coal quality):

$$f_k(x_{ik}) = \frac{x_{ik} - x_k^{\min}}{x_k^{\max} - x_k^{\min}} \tag{6}$$

Based on the value of F_i, coal seams are classified as:

$$\begin{cases} F_i \geq F_{\text{tech}} & \text{Technically feasible} \\ F_{\text{lim}} \leq F_i < F_{\text{tech}} & \text{Conditionally feasible} \\ F_i < F_{\text{lim}} & \text{Technically infeasible} \end{cases} \tag{7}$$

where F_{tech} and F_{lim} are threshold values determined from expert assessments and historical mining performance.

For thin (h_i<0.6 m) and very thin (h_i<0.3 m) seams, correction coefficients are applied to the recovery factor η_i and weighting coefficients w_k, allowing the model to account for unconventional extraction technologies and methane recovery integration.

To assess technical feasibility, comparative methods were applied to evaluate conventional and unconventional coal extraction technologies under CRD conditions. These methods included an analysis of mining system applicability, mechanization level, safety requirements, and compatibility with methane control measures [24]. Emphasis was placed on geotechnological approaches such as hydrodynamic action, underground gasification, borehole-based extraction, and combined mining schemes, with their performance evaluated against geological constraints and gas-dynamic risks.

The economic methodology involved a qualitative and semi-quantitative assessment of cost-forming factors influencing mine profitability. These factors include preparatory workings, safety measures for outburst-prone seams, ventilation and drainage requirements, equipment limitations, and depth-related operational costs [25]. The analysis also incorporated the potential economic benefits of integrating coal extraction with methane recovery and downstream hydrocarbon processing, shifting the evaluation from isolated coal mining toward a value-chain-oriented production model.

Finally, a systems-based methodological framework was applied to substantiate the concept of phased recovery of the CRD coal industry. This framework integrates geological assessment, technological feasibility, and economic justification within the structure of an innovative technology park. The methodology allows for evaluating the transition from resource extraction to processing and product manufacturing, thereby supporting decision-making on the restoration of industrial capacity, employment, and regional socio-economic stability in the post-war period.

3. RESULTS AND DISCUSSION

The most challenging issue in the development of coal deposits at great depths is the extraction of outburst-prone layers. This issue affects all coal mining regions, regardless of their location. The conditions become particularly difficult when developing steeply deeping layers (Fig. 1).

This is due to several factors, the most significant of which are: mining and geological conditions and the small thickness of the layers, the surface technology used for their extraction, the need for the priority extraction of protective safe layers, the manifestation of zones of increased rock pressure (IRP) in the lower and upper parts of the layer in adjacent layers, the need for additional preparatory workings in the side rocks, the complexity of using mechanized systems, and the additional provision of mining sections with measures to control coal outburst hazards, among others.

In the Ukrainian part of the Donetsk Basin, steeply deeping layers are in the Central Region (CRD). These include the "Toretskvuhillia" Association (Toretsk city), "Artemvuhillia" (Horlivka city), and "Ordzhonikidzevuhillia " (Yenakiievo city). Almost all the reserves are classified as high-value coking coal. Therefore, despite the challenging mining and geological conditions, and low mechanization of operations, the development of layers thicker than 0.6 meters continued to depths of up to 1,300 meters. Since 2000, the closure of mines began. Currently, the development of this part of the deposit has now practically ceased. Additionally, due to the hostilities, mine facilities and buildings have been destroyed, leaving the entire region in a depressed state.

Despite the intensive development of the CRD, particularly during the Soviet era, there remains a significant amount of unmined coal layers with high-quality coking coal in this region, which is needed by the state. The problem is that these

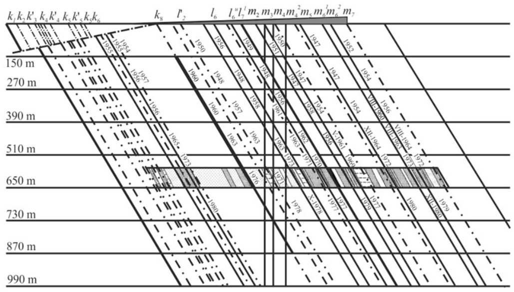

Fig. 1. Cross-section of the rock extension at the monitoring station No. 203 in the conditions of the M. Izotov mine of the "Artemvuhillya" Association, Gorlivka city

Rys. 1. Przekrój wyrobiska skalnego na stacji monitoringowej nr 203 w warunkach kopalni im. M. Izotowa zrzeszenia „Artemwuhillia", miasto Gorliwka

reserves are located at great depths and in layers with thicknesses ranging from 0.1 to 0.5 meters, which were considered non-commercial during the deposit's development.

Moreover, many coal reserves have been left in thicker layers that have not been mined and are in protective pillars, tectonic disturbance zones, and areas prone to collapses and gas-dynamic phenomena. These factors, along with the lack of effective coal extraction technologies, have led to significant costs and the unprofitability of the mines. At the same time, over the entire existence of this coal region, extensive knowledge has been gained about coking coal, which is essential for the metallurgical and chemical industries. More than 350 valuable substances are produced from coal, which are used in industry and agriculture (Fig. 2) [21].

The coking coal of the CRD has very high chemical quality indicators and is a component of the national market for products such as blast furnace coke, coke nut, and coke fines; chemical products of coking and processing, namely: ammonium sulfate, coal pitch, crude coal benzene, coal-tar pitch, coal oils, carbon black, phenolates and polymers of the benzene separation, among others.

The CRD mines served as a research base for gaining knowledge not only about coal but also about the state of the coal-rock massif, which changed with the deepening of mining operations. Moreover, the experience of implementing new technological solutions adopted in the extraction of outburst-prone layers is of great scientific and practical significance [22-25].

Firstly, this involves the large volume of research conducted under the conditions of CRD mines on the stress-strain state (SSS) of the coal-rock massif at great depths. Secondly, coal extraction was constantly accompanied by gas-dynamic phenomena (GDP), leading to significant progress in the development of methods and measures to prevent them [26]. Thirdly, the mining and geological conditions of the layer deposits allow for the simultaneous use of layer and field preparation, as well as combined methods of coal extraction [27].

However, the most important aspect to date is the scientific and practical research into the properties of coal that is needed for the metallurgical and chemical industries [28]. The demand for coking coal for Ukraine's industry and its intensive development is very high. Also, the primary need is the restoration of the population's livelihood and the operational capacity of enterprises [29]. Therefore, it is now necessary to decide whether there is a need to revive the coal industry in the CRD. This is a complex social, scientific, and technical issue at the state level that must be addressed.

Examples of resolving such issues include the creation of innovative infrastructure, technopolises and technoparks, in various areas of territorial development, depending on the functions, scope, and level of cooperation [28-30]. However, this process can only begin after the cessation of hostilities and the return of Donbas to Ukraine.

For many decades, the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine (IGTM NAS of Ukraine) has maintained fruitful cooperation with numerous scientific units and mines in the Central Region of Donbas (CRD) in the study of the properties and condition of the coal-rock massif, ventilation schemes, and the development and implementation of unconventional methods for preventing gas-dynamic phenomena. The institute's employees consistently participate in commissions that review the classification of coal layers by hazard categories related to gas-dynamic phenomena and outburst-prone sandstones; the list of sections and the order of mining particularly hazardous layers prone to GDP; the adjustment of mining operation plans and roof collapse control; the development of measures to combat GDP, during the development of mining sites, and more. Since 1989, the institute's staff has been carrying out hydrodynamic actions during the opening of layers by crosscut, in zones of increased rock pressure (IRP) of stoping faces, in workings through outburst-prone layers, and in the extraction of coalbed methane at CRD mines and other mines in Donbas. The technological solutions developed have proven to be highly effective and unparalleled in the global mining industry [27].

According to the decision of the Permanent Commission on Occupational Safety and Industrial Safety in the Coal Industry of Ukraine (Protocol dated 18.12.2014 No. 4), IGTM NAS of Ukraine has been designated as the specialized leading organization for providing coal mining enterprises with regulatory and legal acts in the field of occupational safety and industrial safety.

The above-mentioned gives IGTM NAS of Ukraine the basis to take a direct role in creating new innovative infrastructure for the reconstruction of CRD, developing and implementing new technical solutions for coal extraction and processing [31]. This will allow for the continued implementation of geotechnological methods and hydrodynamic action regimes in the extraction of coal and methane.

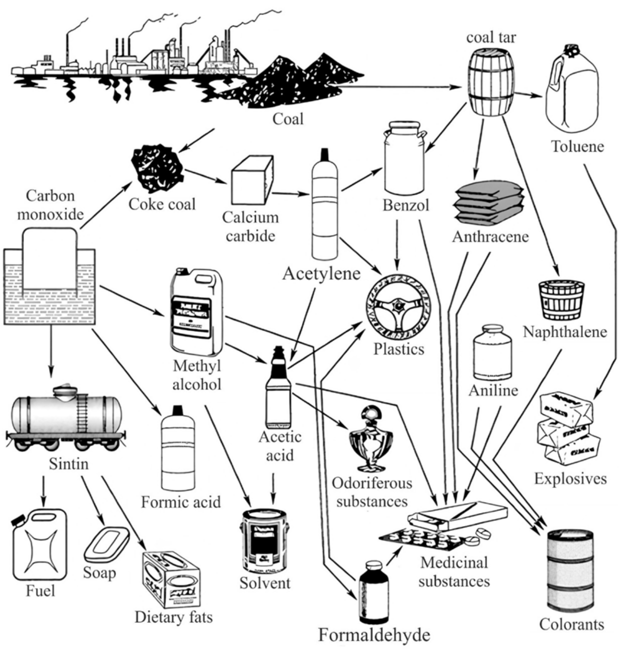

Fig. 2. The most important products obtained during the processing of coal
Rys. 2. Najważniejsze produkty uzyskiwane w procesie przeróbki węgla

However, for this to happen, the Ministry of Energy of Ukraine needs to decide on the creation of a pilot project for innovative infrastructure for the reconstruction of CRD, and research institutes need to conduct such additional studies as:

- to classify coal reserves located in the geological strata;
- to search for innovative technical solutions for coal extraction and processing;
- to justify the feasibility of further developing the coal industry in CRD.

To accomplish these tasks, it is also necessary to resolve the issue of financial support for scientific research.

4. Geological and mining results conditions and factors

As an example of research objects for the purpose of creating a CRD TechnoPark subdivision, let us consider the mining field of the SE "Toretska Mine" of the State Enterprise "ToretskVuhillya." A distinctive feature of this enterprise is that the mining field consists of steeply deeping coal layers ranging from 12 to 45 degrees. This allows for the use of various extraction and mining schemes incorporating elements of geotechnology.

The SE "Toretska Mine" of the State Enterprise "ToretskVuhillya" extracts hard coal, a mineral of national importance. The coal extracted from the mine, according to DSTU 3472-96, is classified as marks G, Zh. It is used in the energy, metallurgical, and chemical industries of Ukraine.

4.1 Geological and Industrial Characteristics of the "Toretska Mine" Field

In terms of geological structure, the field of the mine is situated on the Northern wing of the Main Anticline of Donbas, bordering by extension: to the East – with the "Pivnichna" mine. The technical boundaries of the mine are: to the North – the isohypsa of minus 910 m; to the South – the Axial and Sloping reverse faults; to the West – the Almaznyi thrust fault – reverse fault and the Yeletskyi thrust fault; to the East – the Dyleievskii – reverse fault. The dimensions of the mining field are: by extension – from 3.5 km to 4.5 km; in dip direction – from 2.8 km to 3.8 km, with the total area of the mining field being 13.4 km².

The geological structure of the "Toretska Mine" field is composed of medium carboniferous deposits, with industrial coal-bearing strata associated with the C27, C26, C25 suites deposits. The dip angles of the rocks range from 12 to 42 degrees on the Western wing to 40–45 degrees on the Eastern wing. Within the mining field, there are 45 coal layers with thicknesses ranging from 0.1 m to 1.4 m. A list of layers with thicknesses greater than 0.2 m is provided in Table 1.

The balance of the mine (balance reserves) includes 14 coal layers (m_6 1^{-L}, m_3, l_8^0, l_7^U, l_6, l_5, l_4^U, l_3, l_2^1, l_2, k_8, k_7, k_5^1, k_5). Of these, 10 layers (m_3, l_7^U, l_5, l_4^U, l_3, l_2^1, k_8, k_7, k_5^1, k_5) have industrial significance. The technical boundaries are at horizons: 910 m, 1010 m, and 1110 m. The thickness of the coal layers ranges from 0.52 m to 1.40 m, with the temperature of the surrounding rocks at horizon 710–810 m ranging from 33 to 36°C, and at horizon 910 m – 39°C.

At the working horizon of 810 m, 7 layers have industrial significance. These include layer m_3 on the Eastern and Western wings and layers l_7^U, l_5, l_4^U, l_3, l_2^1, and k_8 on the Western wing. In 2022, layers l_7^U, l_5, and l_3 were developed, and there is potential for further extraction through the reserve group of layers k_L^3, k_2^2, and k_2^U.

The layers are categorized as follows:

- By stability: Stable – l_7^U, l_5, l_3, l_2^1, k_8; relatively stable – m_3, l_4^U, k_5^1, k_5; unstable – k_7.
- By structure: Simple (l_7^U, l_5, l_2^1, k_8) and complex (l_3, k_5^1), with some layers having both simple and complex structures (l_4^H, k_7, k_5).
- By metamorphism: mark G (m_3); mark Zh (m_3, l_7^U, l_5, l_4^U, l_3, l_2^1, k_8, k_7, k_5^1, k_5).

Tab. 1. List of coal layers of the SE “Toretska Mine” of the State Enterprise “Toretskvuhillia”

Tab. 1. Wykaz pokładów węgla w południowo-wschodniej części kopalni „Toretska” Państwowego Przedsiębiorstwa „Toretskwuhillia”

Layer, symbol	General quality indicators of coal				
	layer thickness, m	natural gas content, χ, m^3/t.d.a.m	exit of volatile substances V_{daf} %	thickness of the plastic layer, Y, mm	indicator of the degree of metamorphism, conventional units
Arshynka, $m_6^{1\,L}$	0.47-0.58	5.3-11.1	7.0-35.0	12-22	27.8- 26.0
Kutsyi, m_5	0.25-0.35	5.3-11.1	37.0-35.0	12-22	27.8-26.0
Vanda, m_4^1	0.0-0.28	5.3-11.1	37.0-35.0	12-22	27.8-26.0
Zaichyk к, m_4^0	0.30-0.45	5.3-11.1	37.0-35.0	12-22	27.8-26.0
Pishchanka , m_4	0.1-0.32	5.3-11.1	37.0-35.0	12-22	27.8-26.0
Tovstyi, m_3	1.20-1.8	17.5-17.5	37.3-35.9	15-14	27.3-27.1
Tonkyi, m_2	0.85-0.96	17.5	37.3	15	27.1
Hriaznyi, m_1	0.25-0.26	17.5-17.5	37.3-34.2	15-14	27.3-26.7
Sofiia, l_8^2	0.08-0.26	17.5-17.5	33.0-34.6	17-16	26.1-26.5
Dviinyk, l_8^1	0.25-0.35	17.5-17.5	33.0-34.6	17-16	26.1-26.5
Vodianyi, l_8^0	0.45-0.46	17.5-17.5	33.0-34.6	17-16	26.1-26.5
Puhachivka, l_7^U	0.85-0.93	17.5-17.5	33.0-35.5	17-15	26.1-26.8
Izvestniachka , l_6	0.75-0.80	17.5-20.0	41.7-47.2	16-19	28.0-28.5
Solenyi, l_5	0.65-0.75	3.0-22.5	35.0	17	26.5
Deviatka, l_4^U	0.75	17.5-22.5	34.8	17	26.4
Deviatka, l_4^L	0.70-0.98	3.3-22.5	39.8	17	27.4
Mazurka, l_3	1.26-1.34	3.1-22.5	34.5-35.7	22	26.1
Kyrpychivka, l_2^1	1.00- 1.08	3.10-22.5	34.6-35.2	28	25.6
Kulaha, l_2	0.52	2.5-22.5	32.0-33.9	20	25.6
Mazur, l_1	0.28-0.30	11.0-25.0	33.8-34.5	24-26	25.5-25.7
Kamianka, k_8	0.90-1.04	17.5-22.5	35.4-35.6	25-30	25.5-25.8
k_7^5	0.40-0.45	17.5-22.5	34.5	24	25.7
Soroka, k_7^4	0.35-0.38	17.5-22.5	34.5	24	25.7
Soroka, k_7^3	0.16-0.20	17.5-22.5	34.5	24	25.7
Honchcarka, k_7^2	0.28-0.40	17.5-22.5	34.5	24	25.7
Yuliivskyi, k_7^1	0.07-0.10	17.5-22.5	34.5	24	25.7-25.8
Oleksandrivskyi, k_7	0.74-0.85	22.5	31.5-36.0	20	25.5-26.3
k_6^1	0.30-0.35	22.5	36.0	20	26.3
Anatoliivskyi, k_6	0.25-0.37	22.5	36.0	20	26.3
Piata , k_5^2	0.43	22.5	29.5-33.8	15-19	25.5-26.0
Pidpiatok, k_5^1	1.00-1.05	22.5	29.5-33.8	15-19	25.5-26.0
Velykan, k_5	0.55-0.65	22.5	30.5-32.0	19-22	25.4-25.5
Andriivskyi, k_4^1	0.40	10.5	30.0	14	25.5
Rudnyi, k_4	0.35	10.5	30.0	14	25.5
k_3^2	0.1-0.35	10.5	30.0	14	25.5
Derezovka, k_3	0.47	17.4	30.0	14	25.5
Zolotarka, k_2^2	0.55-0.78	11.1-13.5	27.2	n/a	n/a
Tonenkyi, k_2^1	0.1-0.50	n/a	n/a	n/a	n/a
Umanskyi, k_2^U	0.54-0.96	11.8-17.4	n/a	n/a	n/a

Tab. 2. Reserves of Hard Coal at the SE “Toretska Mine”

Tab. 2. Zasoby węgla kamiennego w kopalni SE „Toretska”

Horizon, m	Balace reserves, th. tons		Industrial reserves, th. tons	Note
	A + B + C_1	incl. C_1		
Horizon 810 - operating	902	902	626	
Horizon 910 m – under construction	6301	6301	4965	
Horizon 910 m – 1010 m	6090	6090	4758	
Horizon 1010- technical boundary	5314	5314	4212	
TOTAL for the mine	18607	18607	14561	

The gas content of the coal layers at the working horizon of 810 m is as follows:

- m_3, l_7^U, l_4^U, l_2^1, k_8 – 17.5 m³/ per ton of dry ash-free mass;
- k_7, k_5^1, k_5 – 22.5 m³/ per ton of dry ash-free mass;
- l_5, l_3, l_2^1 – 3.1 m³/ per ton of dry ash-free mass.

The methane zone is located at a depth of 400–600 m. The category of the “Toretska Mine” regarding methane emission is super-categorized, and it is hazardous for coal dust explosions.

Coal layers m_3, l_7^U, l_4^U, k_8, k_7, k_5^1, and k_5 are prone to sudden coal and gas outbursts, while the others are not. From the 910 m mark, all coal layers are considered hazardous for sudden coal and gas outbursts. Layer l_2^1 is prone to spontaneous combustion, while the others are not.

The main coal-bearing rocks include sandstone, argillite, and aleurolite.

Outburst-prone sandstones: m_3 S m_4^0, l_6 S l_7^U, l_4^U S l_5, l_4^L S l_4^U, k_8 S l_1, k_7^4 S k_7^5, K_9 S k_7^4, k_7^3 S K_9, k_7^2 S k_7^3, k_7 S k_7^2, k_5 S k_5^1.

The mining-geological and mining-technical conditions for developing the coal layers are complex. Factors complicating mining operations include instability of side rocks, the presence of false roofs, tectonically disturbed zones, and floor sliding, as well as the distance of working areas from the shaft yard.

4.2 Hydrogeological Conditions in the Area within the Field of the “Toretska Mine”

The Central Mining Industrial District is located on the Southern slope of the Main Donetsk Watershed, which separates the river systems flowing into the Siverskyi Donets River and the Azov Sea.

The hydrogeological structure of the area includes aquifers in quaternary and carboniferous deposits.

The recharge of these aquifers occurs due to atmospheric precipitation at the outcrop locations of the deposits. As depth increases, the influence of climatic conditions decreases, becoming virtually absent at depths of 800–900 m.

The water-bearing capacity in the region is related to the fracturing of rocks, which reaches depths of up to 1000 m. Fracturing decreases with depth. The water-bearing rocks consist of sandstones and limestones. The depth of groundwater in the aquifer complex of carboniferous deposits in the mining area ranges from 171 to 474 m.

The hydrogeological conditions for developing the coal layers within the field of the “Toretska Mine” are classified as simple.

Tab. 3. Quality Indicators of Coal from the Working Layers of the "Toretska Mine"

Tab. 3. Wskaźniki jakości węgla z warstw eksploatacyjnych kopalni „Toretska"

Index of layer	Ash content A_a, %	Coal moisture content W_a, %	Exit of volatile substances V^r, %	Sulfur S_t^d, %	Thickness of the plastic layer Y, mm
m_6^{1-L}	5.3-24.5	1.7-1.6	34.0-44.1	2.8-5.8	14-25
m_3	5.7-25.4	0.6-1.8	27.9-43.3	0.5-3.5	11-20
l_8^0	4.0-42.2	0.6-1.8	17.8-35.0	0.8-3.2	16-31
l_7^U	5.2-19.1	0.7-1.7	26.2-35.1	1.2-3.9	15-24
l_6	13-36.6	0.5-1.9	32.6-33.8	1.3-5.9	16-25
l_5	8.3-37.4	0.6-1.7	32.1-37.9	2.6-5.6	16-37
l_4^U	21.7-31.2	0.8-1.2	32.7-37.5	2.0-5.1	18-30
l_3	9.2-18.0	0.5-1.2	29.6-37.2	2.9-4.7	22-30
l_2^1	4.2-26.4	0.6-2.4	28.8-36.8	2.1-5.0	25-33
l_2	14.8-25.3	0.6-1.3	29.5-35.7	3.2-5.4	14-36
k_8	7.2-26.0	0.6-0.9	29.9-36.3	3.0-5.5	18-32
k_7	10.4-35.6	0.8-1.2	30.2-33.4	1.3-4.3	15-23
k_5^1	9.5-30.2	1.0-1.11	25.3-34.6	1.7-3.3	14-24
k_5	8.0-32.6	0.6-1.1	25.1-34.9	1.0-4.7	20-30

Tab. 4. Quality Indicators of Coal Established During the Additional Exploration of Layers in Reserve Blocks No. 1 and No. 2 of the "Toretska Mine" field

Tab. 4. Wskaźniki jakości węgla ustalone podczas dodatkowej eksploracji warstw w blokach rezerwowych nr 1 i nr 2 złoża „Toretska Mine"

Index of layer	natural gas content, χ, m^3/t.d.a.m	Coal moisture content W_a, %	Exit of volatile substances V^r, %	Ash content A_a, %	Sulfur S_t^d, %	Thick ness of the plastic layer Y, mm
m_6^2	15-42	0.6-1.6%	34.1-37.6	10.1-36.7	0.8-5.1	11-22
k_2^2	7-19	0.5-1.1	24.0-30.2	6.6-17.9	0.7-2.1	15-25
k_2^U	5-22	0.7-1.1	21.3-31.0	14.8-41.4	0.8-2.4	14-18
k_3^L	3-18	0.5-1.6	25.9-32.6	9.4-21.7	1.0-3.7	19-24
m_6^{1-L}	13-49	0.7-1.6	34.0-44.1	5.3-24.5	2.8-5.8	14-25

4.3 Mineral Reserves and Coal Quality Characteristics

The latest additional exploration of the operated field of the "Toretska Mine", a part of the State Enterprise "Toretskvuhillia" (formerly "Dzerzhinskvuhillya"), was conducted by the Horlivka Geological Exploration Expedition of the "DonbasGeologia" State Geological Enterprise in 1990 – 1994 (Protocol No. 67 of the Scientific and Technical Council of the "DonbasGeologia" dated November 22, 1994).

The reserves of hard coal and associated minerals such as gas (methane) and the components (germanium) at the mine are recorded in the State Balance of Mineral Reserves of Ukraine as of January 1, 2023, and are as follows:

- Coal (thousand tons): balance reserves – C_1=18607, C_2=2089; off-balance reserves – 4955; industrial reserves – 14561;
- Methane (million m³): balance reserves – C_2=404.8, C_3=1103.8 (including associated layers C3=889.4);
- Germanium (tons): balance reserves – C_1=45.1, C_2=4.0.

The reserves of coal and germanium were approved by the State Committee for Reserves of the USSR (Protocol No. 8413 dated December 7, 1979) and the Scientific and Technical Council of State Mining Enterprise "DonbasGeologia" (Protocol No. 67 dsted November 22, 1994). Methane reserves were approved by the State Committee for Reserves of Ukraine (Protocol No. 1610 dated October 23, 2008).

As of January 1, 2023, the industrial reserves of hard coal in the subsoil for the "Toretska Mine" of the SE "ToretskVuhillia" across the horizons and in total amount to 14561 thousand tons (Table 2). With a production capacity of 110 thousand tons of coal per year, the mine's operational life is estimated to be 133 years. Key quality indicators of the coal extracted from the mine are listed in Table 3.

During the additional exploration of the mine field, from the outcrop of the layers to the isohypse of 1500, at the points where the layers intersect with boreholes, the working thickness of the coal layers that were previously not considered in the reserve, the calculation was established: m_5 (thickness 0.25–0.35 m), m_4^0 (thickness 0.30–0.45 m), m_2 (thickness 0.20–0.35 m), m_1 (thickness 0.20–0.30 m), l_8^2 (thickness 0.20–0.35 m), l_4^L (thickness 0.30–0.50 m), l_1 (thickness 0.20–0.40 m), k_7^5 (thickness 0.40–0.50 m), k_5^2 (thickness 0.30–0.40 m), k_4 (thickness 0.30–0.45 m), k_3^L (thickness 0.40–0.50 m).

Simultaneously, an estimate of additional reserves for the layer m_6^2, which adjoins the mine field from the outcrop to the isohypse of 1500, as well as for the layers k_2^2–Zolotarka and k_2^u–Uman, which are not included in the balance of the "Toretska Mine" field but are reserve blocks No. 1 (from the isohypse of 910, which is the technical boundary of the mine field up to the isohypse of 1500) and No. 2 (below sthe eam k5 from the isohypse of 300 to the technical boundary of the mine field), was conducted.

Additionally, the reserves were calculated for coal layers not included in the balance of approved layers for the "Toretska Mine" field. Further investigations were conducted on the coal layer m_6^2, which adjoins the mine field from the outcrop to the isohypse of 1500. Its thickness was established as 0.54–0.57 m, with reserves of category C_2=4030 thousand tons, and coal quality indicators are presented in Table 4.

The reserves of coal in the layers have been calculated as follows:

- k_2^2 – Zolotarka, in block No. 1, with layer thickness of 0.55–0.58 m, the balance reserves in category C_2 are 2,452 thousand tons. In block No. 2, with layer thickness of 0.54–0.78 m, the reserves in category C_2 are 2409 thousand tons, totaling 4,861 thousand tons;
- k_2^u – Umanskyi, in block No. 1, with layer thickness of 0.54–0.79 m, the balance reserves in category C_2 are 2,074 thousand tons. In block No. 2, with layer thickness of 0.54–0.78 m, the reserves in category C_2 are 3225 thousand tons, totaling 5299 thousand tons;
- k_3^L – Derezovka Lower, with layer thickness of 0.40–

0.50 m, in block No. 1, the balance reserves in category C_2 are 1746 thousand tons. In block No. 2, the reserves in category C_2 are 1578 thousand tons, totaling 3324 thousand tons;

- $m_6^{L\text{-}l}$ – Arshynka Lower, with layer thickness of 0.47–0.58 m; this layer has not been developed.

The balance reserves in category C_1 in the "Toretska Mine" field (from the surface to the technical boundary of the mine field, isohypsa -910) amount to 3106 thousand tons. In reserve block No. 1, the balance reserves in category C_2 are 1,222 thousand tons.

As a result of additional exploration, the total coal reserves for the layers m_6^2, k_2^2, k_2^u, k_3^L, and $m_6^{1\text{-}L}$ amount to more than 18500 thousand tons.

Additionally, within the mine field, there are 20 layers with thicknesses ranging from 0.1 to 0.5 m which reserves are not accounted for anywhere.

4.4 Technology for Developing Layers Adopted at the Mine

The "Toretska Mine" field of State Enterprise "Toretskvuhillia" is accessed via three vertical shafts and surface horizontal drifts. Shaft No. 1 is a man/freight shaft, bored to a depth of 1043 m, with a diameter of 6.5 m and a cross-section of 33 m². Shaft No. 2 is a skip shaft, bored to a depth of 916 m, with a diameter of 6.0 m and a cross-section of 28 m², used for coal delivery and discharge of the outlet ventilation jet. Shaft No. 3 is sealed, bored to a depth of 1023 m, with a diameter of 8.0 m and a cross-section of 503 m², and is unreinforced.

The mine has adopted a horizont-based mine field preparation scheme. On levels 110, 210, 310, 410, 510, 610, 710, and 810 m, main and intermediate crosscuts have been driven. Levels 110, 210, 310, 410, and 610 m have been worked out and sealed. Levels 710 and 810 m are operational. Level 910 m is under construction. Level 510 m is used for drainage water pumping.

The layer preparation scheme is surface based (layered). The haulage gates and air roadways are driven through each layer being developed and are grouped into field drifts with haulage of freight to the front and rear intermediate crosscuts.

The layer development system is continuous and combined.

Coal extraction in the longwalls is carried out using jack hammers,

less frequently with combines due to the intensive development of tectonic disturbances in the mine field. Mining pressure control is maintained with timber supports, full collapse, and gradual subsidence. The method of transporting coal from the mining face is through enamelled transport chutes and sheets.

The maximum depth of development is 910 m. The lower technical boundary is minus 910.

The layer dip ranges from 10° to 49°, with a predominance of 27–45°.

The ventilation scheme is central, with a suction ventilation system. Fresh air enters the mine through the man/haulage shaft No. 1 and exits through the skip shaft No. 2.

The water drainage scheme is two-stage, with the main water drainage installation located at the horizon level of 810 m and an additional water drainage installation for pumping at the horizon level of 510 m.

The main type of transport in the mine is a locomotive haulage. The track gauge is 600 mm, with the Waggonette ВГ (FW – freight waggonette) –1.3.

4.5 Techno-technological solutions

The conducted research highlights the following key points:

Firstly, the exploration results have established that within the "Toretska Mine" field, there are 18607 thousand tons of balance coal reserves, of which 14561 thousand tons are industrial reserves. With a production capacity of 110 thousand tons of coal per year, the mine's service life is projected to be 133 years.

Additionally, there are 20 layers within the mine field with thicknesses ranging from 0.1 to 0.5 m, of which 11 layers (m_5, m_4^0, m_2, m_1, l_8^2, l_4^1, l_1, k_7^5, k_5^2, k_4, k_3^l) extending to isohypsa -1500 have working thicknesses of 0.25 to 0.5 m. These coal reserves are not currently accounted for.

Secondly, the technology for the development of suites of thin, steep, and steeply deeping layers, considering their gas-outburst hazard, is associated with significant costs for preparatory and preventive work, complex mining and geological conditions, and the lack of high-quality and effective coal mining equipment, and automated technological processes. This combination leads to high costs and the unprofitability of mines in the CRD. However, the coal marks, primarily K and Zh, have high-quality characteristics necessary for the metallurgical and chemical industries and are an integral part of the national market.

Thirdly, in the CRD mines, the layers thicker than 0.6 m are mined using jack hammers, shield complexes, and other equipment. In some cases, the layers with a thickness of 0.5 m are mined using jack hammers and are considered as protective layers. All other layers are not considered due to the absence of technological solutions for their effective development.

The closure of CRD mines since the early 2000s has led to the loss of significant coal deposits in already prepared horizons. The aim of this program was to close unprofitable mines. However, it is known that the entire coal industry in Ukraine is unprofitable. Currently, it is impossible for mines to profit from coal mining alone. Profit can be obtained by either the state or by a large corporate structure that owns mines, coal and methane processing plants and product sales facilities. For example, "DTEK Energo" profits from electricity sales, chemical products, and metallurgical products, which allows them to update mining equipment and increase coal production. Another example is the "O.F. Zasiadko Mine", where integrated coal and gas mining, electricity production, and chemical methane processing have also generated additional profits.

There are no existing examples of profitable operation of CRD mines yet. However, if considered comprehensively, given the high-quality coal for the chemical and metallurgical industries and the potential for reviving coal mining in the CRD through the implementation of modern geotechnologies for hydrocarbon extraction and processing at newly established enterprises within the region, such revival appears very promising.

Currently, despite complex political, economic, and technical conditions, the state needs to support the operational mines and other enterprises that remain and operate in the region. At the same time, it should support research institutions and commercial entities involved in developing new technologies for mineral resource exploration, improvement, and development of technological processes for the extraction and processing of solid, liquid, and gaseous hydrocarbons.

In this regard, the IGTM NAS of Ukraine has already developed effective high-tech solutions, as previously mentioned. This provides grounds for IGTM NAS of Ukraine to participate directly in creating new innovative infrastructure for the revival of the CRD, developing, and implementing new research directions for coal and methane extraction and processing.

Mechanization of mining operations using geotechnological methods of mining outburst-hazardous layers and reduction of overall costs by increasing coal production with simultaneous production and processing of coal methane is the first stage of the CRD coal industry restoration.

The second stage involves improving existing technological solutions for mining or cutting coal from layers with thicknesses ranging from 0.2 to 0.6 m and adapting these solutions into technological schemes for layer preparation, development, and mine ventilation [32].

The third stage consists of developing and implementing geotechnologies for the extraction and processing of coal from residual reserves through surface boreholes to a feasible technological depth [33]. For example, this might involve methods such as hydrodynamic actions, gasification, pyrolysis, and mining techniques, with raw material processing directly at the extraction site and transporting the finished products to other regions.

Each development stage requires additional comprehensive research: mining and geological conditions; technologies for preparing and extracting reserves; development of technological schemes and method parameters; scientific justification for the most effective direction of technological process development. It is necessary to conduct a systematic analysis of coal reserves within CRD mines. This includes studying the natural and topographic features of the region, which significantly affect raw material transportation. Much has already been defined in these areas [31-35]. Additionally, there are well-known, highly effective technologies and methods for mining minerals: open-pit and underground methods, combined mining methods, geotechnologies for mineral extraction, and processing technologies.

In the CRD, the use of known non-traditional scientific and technical solutions has already been tested: underground gasification; boring methods for coal extraction; rope saw methods for coal extraction; hydraulic methods for coal undercutting and hydrodynamic actions through boreholes for methane extraction [24, 27, 36]. These methods or their analogs have also been tested in other coal mining regions worldwide.

From the analysis of modern methods for researching geotechnological solutions used for non-traditional methods of influencing gas-saturated outburst-hazardous coal layers, several directions for restoring coal mining in the CRD are possible.

For example, one of the first test sites for underground coal gasification was Mine No. 4 "Pidzemgas," located in Horlivka. Initial tests and the search for an optimal layer ignition scheme in 1934–1936 allowed stable gas formation. The development of the first industrial Underground Coal Gasification (UCG) station in Lysychansk played a crucial role, with scientists from Dnipro Technical University making significant contributions. This project highlighted the innovative approach of Ukrainian scientists to the field of underground coal gasification (UCG) [37]. Collaboration between the University specialists and industrial engineers led to the creation of advanced technological schemes adapted to the gasification process [38].

One of the main innovations was the reversal of airflow direction [39] and formation of bidirectional artificial shells [40]. These technological solutions contributed to the formation of stable reaction channels in coal layers, significantly enhancing the efficiency and control of the gasification process [41] and allowing for the economic justification of UCG [42, 43]. The research results evaluated the environmental impact of UCG compared to traditional coal mining methods [44, 45]. Coal gasification technology is increasingly attracting attention and being refined. To improve the efficiency of the gasification process and maximize coal resource utilization, particular attention is given to coal type, operational parameters, and process components (temperature, pressure, catalysts, CO2 emissions, etc.) [46-50].

Based on the analysis of technological processes occurring during underground coal gasification (UCG) and the methods for preparing technological boreholes, the creation of new geotechnologies involving hydrodynamic action [27] and other methods of thermal or chemical coal conversion underground appear very promising.

Auger mining technology is worth paying attention to. On the mines of Donbas and the Lviv-Volyn Basin, BUH-3 installations were used. The drawback of this technology is that over 70% of the time is spent on auxiliary processes and the relatively shallow depth of boring. However, its use in complex conditions and in the development of reserves competes with mechanized complexes [24]. This technology has also seen further development. Currently, it is considered as a borehole technology for coal extraction (auger mining technology) [51,52]. The experience of using auger machines from companies such as "Cardox", "Joy", and "Korfmann" in the USA, England, Germany, Australia, as well as in China and Turkey indicates that this method of boring coal should be used in conditions where extraction by other methods is unavailable or economically unfeasible.

Another method that has been tested in the mines of CRD, Germany, England, and Poland is the extraction of coal using saw-like aggregates [24]. In this method, the destruction of the coal mass is accomplished using a special mechanism – a saw. The saw is a cable with a diameter of 20–22 mm, equipped with cutting teeth [3, 24]. The reciprocating motion of the cable (saw) is provided by winches installed on the ventilation drift. The broken coal, under its own weight, shifts to the haulage gate.

The first experience of using cable saws in CRD was obtained under the conditions of Mine No. 1-2 "Chervonyi Zhovten" and Mine No. 10 named after Artem. In Germany, England, and Poland, the saw had a different design, but the principle of its movement in the face was the same. Experimental tests showed that the technological scheme of coal extraction using cable saws is effective under favorable conditions. However, further development and research of this method for extracting thin steeply deep layers were discontinued due to the availability of cheaper energy sources – crude oil and natural gas.

At the same time, an analysis of the practical use of gasification, boring, and sawing technologies in CRD and other coal deposits abroad, such as in the USA, Germany, and Poland, shows that the combination of these technologies with modern coal processing methods can be an effective way to revive the coal industry in CRD Ukraine, support the livelihood of the population, and ensure the operability of enterprises.

5. CONCLUSION

This study substantiates a staged approach to the revitalization of the coal industry in the CRD based on the integration of modern geotechnological solutions, methane utilization, and the development of residual coal reserves. The proposed framework addresses both technological and socioeconomic challenges associated with the sustainable redevelopment of coal mining regions.

At the first stage, the application of advanced geotechnologies enables an increase in mechanization levels, enhances operational safety in outburst-prone seams, and reduces production costs through higher coal output combined with the simultaneous extraction and utilization of coalbed methane. This stage establishes the technological basis for improving mine safety and energy efficiency.

The second stage focuses on the adaptation and optimization of existing boring and cutting technologies for coal seams with thicknesses of 0.2–0.6 m. These technologies are integrated into comprehensive schemes for seam development and mine ventilation, ensuring stable and efficient extraction under complex geological conditions. The novelty of this stage lies in the systematic adaptation of proven methods to thin and ultra-thin seams within a unified technological framework.

The third stage proposes the development and implementation of surface-borehole-based geotechnologies for the extraction and processing of coal from residual reserves to a technologically feasible depth. Technologies such as underground coal gasification, hydrodynamic treatment, pyrolysis, and borehole mining are considered as complementary solutions. A key contribution of this stage is the justification of on-site raw material processing followed by the transportation of finished products, which is shown to be a critical technical and economic factor for the viability of such projects.

From a regional development perspective, the results of this study support decision-making aimed at restoring local livelihoods and improving the efficiency of coal industry enterprises in the CRD. The practical implementation of the proposed approach requires: (i) a comprehensive feasibility study based on the classification of coal reserves and the selection of innovative extraction and processing technologies; (ii) the establishment of a regional technopark to facilitate infrastructure recovery and innovation-driven development; and (iii) the realization of pilot projects demonstrating the technical, economic, and environmental effectiveness of coal extraction from thin and ultra-thin steeply dipping seams.

Overall, the proposed staged concept provides a scientifically grounded and practically applicable pathway for the sustainable transformation of the coal industry in the CRD, aligning technological innovation with regional economic recovery.

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Zarządzanie czynnikami technicznymi i ekonomicznymi w koncepcji wydobycia, produkcji i przeróbki węglowodorów

Niniejszy artykuł analizuje perspektywy powojennej rewitalizacji Centralnego Regionu Donbasu (CRD) poprzez utworzenie innowacyjnego parku technologicznego opartego na wykorzystaniu zasobów węgla i węglowodorów, wykorzystując jako studium przypadku kopalnię Toretska należącą do przedsiębiorstwa państwowego Toretskugol. W artykule dokonano oceny bilansowych zasobów węgla w polu wydobywczym oraz przeanalizowano istniejące i nowe technologie wydobycia i przeróbki związków węglowodorowych. Kopalnia Toretska posiada około 18,6 mln ton zasobów węgla, w tym 14,6 mln ton zasobów przemysłowych. Przy obecnej technologii wydobywczej i rocznej zdolności produkcyjnej wynoszącej 110 tys. ton, szacowany okres eksploatacji kopalni przekracza 130 lat. Oprócz zasobów konwencjonalnych, złoże obejmuje 20 pokładów węgla o miąższości od 0,1 do 0,5 m, z czego 11 pokładów ma miąższość eksploatacyjną od 0,25 do 0,5 m do poziomu izogipsu −1500 m. Zasoby węgla to przede wszystkim wysokiej jakości węgle K i Zh, które mogą zawierać ponad 350 cennych substancji do zastosowań przemysłowych i rolniczych. W artykule zwrócono uwagę na niekonwencjonalne podejścia do wydobycia węgla i metanu, w tym technologie górnicze dla cienkich i bardzo cienkich pokładów oraz odzysk metanu z wyeksploatowanych wyrobisk górniczych. Chociaż stabilna rentowność wydobycia cienkich pokładów nie została jeszcze udowodniona w praktyce, zaproponowano kompleksowe podejście integrujące zaawansowane geotechnologie, przerób węglowodorów i symbiozę przemysłową. Opierając się na doświadczeniu dużych przedsiębiorstw energetycznych, takich jak DTEK Energo, utworzenie innowacyjnego parku technologicznego CRD mogłoby umożliwić generowanie dodatkowej wartości i przyczynić się do zrównoważonej odbudowy regionu w okresie powojennym.

Słowa kluczowe: *wydobycie węgla, cienkie pokłady węgla, odzysk metanu, technologie górnicze, innowacyjne rozwiązania, technopark, przywracanie źródeł utrzymania*