





# Artificial intelligence technologies in the mining industry: Economic and legal assessment

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## Abstract

**Purpose.** Research and development of an economic and legal concept for the use of AI-technologies in mineral mining based on an experience analysis of their application in global mining practice, including assessment of legal and technological support.

**Methods.** The research was conducted using a review-based economic and legal approach, consisting of assessing and analysing the symbiosis of positive and negative aspects of AI-technology implementation in mining enterprises. This paper reviews legislation using legal analysis processes, including comparative, systematic, and formal-legal methods, which ensure the regulation of AI-relations. To study the key aspects accompanying the processes of using AI-technology in mining enterprises, European, Ukrainian and Kazakh regulations were systematized, and econometric modelling of the effectiveness of using AI-technologies was performed to assess operating costs.

**Findings.** The subject structure and principles of AI-relations, as well as the scope of application of AI-technologies in mining enterprises, which should be taken into account when implementing them in the mining industry, have been identified. Requirements have been formulated for AI-systems that are used and/or may be used in the mining industry. A group of barriers accompanying the use of AI-technologies in mining enterprises has been systematized and analyzed. The author's AI-Concept framework for the mining industry has been developed. A set of preparatory measures for the implementation of AI-technologies is proposed, and the directions and factors accompanying their use in mining enterprises are examined.

**Originality.** A model of the AI-Concept for the mining industry has been developed, as well as conceptual recommendations for the creation of AI-enterprises, which, in the presented, integrated form, have not been developed in the legislation and scientific literature of the world's leading mining countries.

**Practical implications.** The research results can be used in the process of developing economic and legal relations in the mining industry. Conceptual recommendations will be useful in the phased creation of mining AI-enterprises. Their implementation will enable the resolution of pressing social-economic, investment, and environmental issues in the context of a fair transformation of mining regions.

**Keywords:** *AI-technologies; extraction; economic assessment; legal regulation; industry reform; mining industry*

## 1. Introduction

Artificial intelligence (AI) technologies are rapidly changing approaches to the mining industry, including extraction sector, providing new opportunities for optimizing production processes, improving safety and reducing environmental impact. According to the Order of the Cabinet of Ministers of Ukraine dated 13.04.2024, No. 320-r [1], which approved the Concept of the State Targeted Scientific and Technical Program for the Use of AI Technologies for the Period until 2026 and based on the provisions of the Mining Law of Ukraine [2], [3], the mining industry is defined as one of the priority sectors of the economy, where these technologies are actively implemented. This underscores the

importance of digitalization to enhance the competitiveness of the industry and its sustainable development. In addition, it should be noted that on 15 May 2025, Ukraine signed the Framework Convention on Artificial Intelligence (AI) of the Council of Europe on Human Rights, Democracy and the Rule of Law. In essence, this is the first international document that establishes basic principles for AI-regulation. Similarly, in Kazakhstan, the Law of the Republic of Kazakhstan “On Informatization” dated 24.11.2015 No. 418-V [3] and the Concept of Digital Transformation of the Mining Industry until 2025 define AI as a tool for improving the efficiency of mineral extraction in mining enterprises such as Kazakhmys and KazMunayGas [4], [5].

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Modern AI-technology development opens up new horizons in the field of mineral mining, covering technical, legal and economic aspects. The growing complexity of mining operations, high risks and increasing volumes of industrial data create conditions in which the use of AI becomes not only expedient, but also necessary. In recent years, there has been active implementation of machine learning methods, neural networks and hybrid intelligent systems in geological exploration, drilling, resource management and risk assessment. At the same time, the issue of legal regulation and ethics of AI use in industries with a high level of potential threat and public significance remains relevant.

### 1.1. Problem formulation

As global practice shows, the introduction of AI-technologies in mining enterprises is accompanied by significant advantages. For example, the performance of equipment increases, as the latest systems can predict technical condition and prevent breakdowns. In addition, process automation reduces the influence of human error, increasing the level of safety for workers [6]. Such innovations facilitate accurate resource accounting and cost reduction, which is crucial in conditions of competitive market and the preservation of coal mining for the Ukrainian economy in the process of decarbonisation [7].

At the same time, the economic benefits of AI-technologies must surely be combined with legal guarantees. For example, processing the large volumes of data needed to operate AI-systems in mining enterprises requires clear legal regulation that will protect privacy and AI-rights [8]. At the same time, there are legal liability issues related to possible accidents or errors caused by the use of AI-technologies. Here, the issue of establishing the entity on which it would be lawful to impose liability [8] appears to be extremely important, serving as the background source for the general thesis on the significance of legal regulation of mineral resources in the industry.

Equally important are the environmental and social aspects of using AI-technologies in the mining industry. At the same time, it should be recognized that such innovations help to better control the environmental impact of mining operations, monitor dust and gas emissions, and optimize waste management [9], [10]. In a social context, AI-technologies are primarily aimed at creating safer working conditions, reducing injury risk, promoting the development of new approaches to employment in the industry and/or in the mining region [11], [12].

Nevertheless, the implementation of AI-technologies faces certain barriers. The high cost of the latest technologies and the lack of a sufficiently developed legal framework pose serious challenges for many mineral mining entities. In addition, the risks of cyber threats and the complexity of integrating digital systems into traditional production processes also remain relevant for research review and analysis. The Republic of Kazakhstan faces similar challenges: the lack of detailed AI norms in the Law on Subsoil, as specified in Decree No. 1042 [13], which delays implementation by 1-2 years. Equally important are issues related to the economic-legal assessment of the consequences of introducing such innovations, both those directly related to mining and geological relations [12], and those related to the AI-field accompanying them [14], [15].

At the same time, AI-technologies can truly transform key aspects of the mining industry, enabling technological process optimization, improved safety, and reduced costs. However, their use raises issues related to liability regulation, data protection, operating standards, and labor market adaptation to new realities [16]. Therefore, this research proposes conducting a comprehensive study of the economic-legal consequences of applying AI-technologies in mining enterprises, including an assessment of the prospects for their implementation. At the same time, attention should be paid to the issues of forming sustainable regulatory frameworks capable of ensuring a balance between innovation and security, as well as considering the prospects for the use of AI-technologies covering a range of areas from exploration and field development to AI-based mining management, economic priority, feasibility and legal protection of AI-solutions.

### 1.2. Analysis of recent research and publications

The results of the study [16] show that the application of AI and machine learning in the coal industry demonstrates significant potential for ensuring sustainable and safe production. Particular attention is paid to optimizing the operation of autonomous equipment, predictive technical maintenance and monitoring of environmental parameters. Despite the positive effects, challenges remain in terms of data quality and staff adaptation.

Denisa, M.A. et al. [17] demonstrate that implementing AI in the mining industry minimizes the risk to workers' lives by automating processes, improving production efficiency, and ensuring production continuity. Significant improvements are noted in the areas of occupational safety, productivity and economic performance. The paper highlights the role of AI as a key factor in transforming the industry towards a safer and more rational model.

Hyder Z., Siau K., & Nah F. analyze the implementation of AI, machine learning and autonomous technologies in the mining industry [18]. Both economic benefits – cost savings, increased safety and continuity of the production cycle – as well as issues related to financing, staff qualifications and the regulatory environment are noted. Findings are based on industry analysis and serve as the basis for forming a balanced AI implementation strategy. Unlike their approach, our analysis is based on a review of acts without primary interviews.

Rosienkiewicz M. explores hybrid models for predicting spare parts demand in the mining industry [19]. It is proposed to combine time series methods with AI-models, including neural networks and support vector machines. Empirical testing on copper mine data showed an increase in prediction accuracy, which is of direct importance for the optimization of warehouse and logistics processes at enterprises.

One of the important components of the economic-legal assessment of digital technologies in the mining industry is the perception of innovation by employees. Yudhistrya W.I. & Srinuan C. identify key factors influencing the adoption of generative AI in their study: staff attitude, expected usefulness, and management support. The findings highlight the secondary role of the regulatory frameworks and the importance of the internal organizational environment [20].

Ratov B. et al. [21] discuss the use of machine learning methods for modelling mechanical processes in the mining industry, focusing on legal aspects. Algorithms successfully used to predict rock properties in order to optimize drilling

and reduce accidents are described. The importance of correct model configuration and the availability of high-quality data is emphasized. It is proposed to integrate AI into geological legislation to increase the transparency and manageability of technologies.

Sardjono W. & Perdana W.G. describe the application of AI in the context of Industry 4.0 using the example of mining company PT Delta Dunia Makmur TBK [22]. Examples of improving operational efficiency through process automation, Big Data analysis and fuel consumption optimization are provided. The dependence of AI on the quality of source data is emphasized, which requires legal and institutional regulation in the mining sector.

An analysis of technological trends in the Indonesian mining and quarrying industry in [23] revealed a low level of implementation of promising digital solutions, despite the active use of AI-analytics. Particular attention is paid to the Internet of Things, while technologies such as Augmented Reality (AR) and Blockchain remain in their infancy. There is a need for strategic adaptation of new technologies, taking into account the exhaustibility of resources.

Bendaouia A. et al. [24] demonstrate that the digitalization of flotation processes using ConvLSTM-type hybrid neural networks demonstrates the effectiveness of AI in real-time control of technological parameters. The proposed approach enables accurate prediction of concentrate composition, improving the overall beneficiation efficiency. This confirms the feasibility of large-scale implementation of AI in processing operations in mining enterprises.

The study by Sharifzada S. & Naghiyev N. focuses on the potential of AI applications in space resource mining, emphasizing the need for autonomous navigation systems, robotization, and data analytics to optimize missions [25]. The authors emphasize that, despite the high economic costs, that AI is becoming the key to implementing sustainable projects in space. This approach opens up prospects for the creation of new legal and economic frameworks beyond the Earth's borders.

Modern approaches to the use of AI-technologies in mining industries, particularly in the oil and gas industry, indicate a profound transformation of production processes and the need for their economic-legal reassessment [26]. The study highlights the potential of AI and cloud computing to improve field development productivity and efficiency, particularly in the context of enhanced oil recovery technologies, while also identifying existing constraints and challenges.

Haroon S. et al. [27] examine the reasons for the slow adoption of AI-technologies in the oil and gas industry, despite their success in other sectors. The authors focus on structural barriers and the need to modernize digital infrastructure for effective AI applications. Examples of successful AI integration in geophysics, well injection design, and mining are provided. The importance of data quality and structure for model training is emphasized, and solutions are proposed to overcome "digital bottlenecks" in the industry.

Mohaghegh S.D. & Khazaeni Y. summarize the development of AI in the oil and gas industry over the past two decades, focusing on hybrid systems combining neural networks, evolutionary algorithms, and fuzzy logic [28]. Examples of practical application of these approaches in interpreting logging data, reservoir characteristics and selecting wells for stimulation are also discussed. The study demonstrates the high efficiency of complex AI-methods in solving complex top-level hydrocarbon production tasks.

Min C. et al. emphasize the need for interpretability of machine learning models, which is particularly relevant for increasing trust and implementing AI in the oil and gas industry. The authors propose using both post-hoc methods (e.g., SHAP and LIME) and cause-and-effect approaches, emphasizing the role of interpretability as a critical factor for successful AI integration [29]. Liu H. et al. examine large-scale artificial intelligence models (such as linguistic and multimodal models) that are at an early stage of application in the oil and gas sector. The authors highlight key challenges: lack of data, high development costs and low autonomy of algorithms, while emphasizing the strategic importance of these models for digital energy development [30].

Ramachandran K.P. et al. conduct a comparative analysis of ANN and XGBoost algorithms in the task of monitoring the state of drilling equipment. The study confirms the effectiveness of AI-methods for predictive diagnostics and failure prevention, demonstrating the advantages of XGBoost in the accuracy of technical state recognition based on acoustic emission signals and wavelet transform [31].

The study by Cedeno M.A. et al. examines the use of artificial intelligence to model the adsorption of asphaltene on nanoparticles in oil production [32]. The study covers a wide range of oil types and nanomaterials, including silicon dioxide and aluminium oxide. AI-models capable of accurately predicting adsorption isotherms are proposed, which allows for more effective management of asphaltene sediments. The results obtained demonstrate the potential of AI in the field of nanotechnology in oil production. In their next paper, Cedeno M.A. et al. [33] expand the scope of their previous research by including additional types of nanoparticles (e.g., cerium) and significantly increasing the volume of experimental data. Both universal and specialized AI-models were developed to predict asphaltene adsorption. The study confirms the practical importance of using AI to optimize oil production parameters, taking into account nanotechnology.

Adityawarman T. et al. [34] conducted a review of risk-based inspection methods in the oil and gas industry from an artificial intelligence perspective. They examined machine-learning algorithms such as decision trees, logistic regression, and SVM, used to assess the remaining useful life of equipment. Authors emphasize the importance of AI in ensuring the reliability and safety of production processes. The study stands out for its integrated approach to handling unstructured inspection data. Mohamed Almazrouei S. et al. focus on predictive maintenance issues for water injection pumps, highlighting the importance of algorithmic optimization, data quality and interpretability in the decision-making process. The study offers a systematic approach to selecting AI-models, focused on improving equipment reliability and reducing costs, which updates the economic-legal assessment of AI implementation in the context of operational activities [35].

The study by Jaara A. et al. is devoted to a general analysis of the impact of AI on the oil and gas industry. The authors emphasize the role of AI as a technology that shapes the future of the industry by addressing key production challenges. The study provides an overview of potential uses for AI, including efficiency improvement and process optimization. The strategic importance of digitalization of the industry using AI is emphasized [36].

Review [37] systematizes modern approaches to the application of AI and machine learning in the oil and gas indus-

try, with a focus on the processing and interpretation of large data sets. Methods used at various stages of oil exploration and production are analyzed. The advantages of AI in automation, cost reduction and improved analytical decision accuracy are highlighted. The study is of an applied nature and is aimed at implementing AI in production processes.

Choubey S. & Karmakar G.P. analyze the potential of AI and ML in the context of decision-making based on predictive analytics in the oil and gas sector. Emphasis is placed on using both historical and operational data to increase productivity and streamline processes. The study presents modern analytical models used from exploration to product distribution. The study forms a methodological basis for selecting appropriate digital solutions in the industry [38].

A literature review confirms the potential of AI in transforming the mining industry, where economic assessment (Return on Investment models or ROI-models, for reducing costs by 15-25%) is combined with legal regulation (liability for algorithms, risk insurance). In Ukraine, digitalization is based on national priorities (CMU Order No. 320-r, 2024), while in Kazakhstan it is based on industry concepts until 2025, with examples from copper mining. Global experience [18], [27] highlights barriers, but our concept integrates them into a single framework for sustainable implementation.

Analyzed studies show large-scale and multifaceted implementation of AI-technologies in the mining industry. Scientific papers highlight the potential of AI to improve the efficiency, safety and sustainability of technological processes – from exploration to resource transportation and processing. However, against the background of technological progress, pressing issues are emerging related to the need for regulatory and legal support for AI-technologies, ensuring the transparency of algorithms, protecting the rights of participants, and preventing social risks. Thus, further development of AI in the mining industry requires an interdisciplinary approach that combines technical, economic and legal components. At the same time, gaps in this area should be noted. Above all, this is the lack of a comprehensive economic-legal assessment of AI in mining, taking into account the post-Soviet context in both Ukraine and the Republic of Kazakhstan. At the same time, studies focus on technologies, without integrating legal and national peculiarities [7]. As an empirical case, it is worth highlighting the example of the Kazakhmys enterprise [5], when the draft Law on AI [39] aims to fill gaps by regulating ethics in the mining process.

### 1.3. Identification of unresolved parts of the general problem

Issues remain unresolved regarding the integration of Kazakhstan's legal framework (Law "On Informatization") with AI in the mining of solid minerals; a comparative analysis with Ukraine (post-war transformation under CMU Order No. 320-r) is not found in the literature. Moreover, no comprehensive models have been developed that take into account the "black box" in an economic-legal context, with a focus on ROI and risk insurance for post-Soviet countries.

### 1.4. Formulating the research purpose and setting the objectives

The purpose of the paper is oriented towards the formation of an economic-legal framework for AI in mineral mining, based on international experience and the specifics of enterprise transformation in Ukraine and Kazakhstan.

To achieve the purpose set, the following objectives should be achieved:

- conduct a comparative review of legal norms governing AI-relations in Ukraine, Kazakhstan and the EU;
- assess the conditions for using AI at mining facilities, taking into account technological and social factors;
- identify constraints on the implementation of AI in the industry;
- to synthesize an economic-legal model for AI-technologies.

The sequence of task resolution stems from the priority of international law over national law and the practical stages of mining technology.

## 2. Research methods

Research into the application of AI-technologies in the mining industry is conducted in stages, with a focus on an integrated approach covering key technological, economic, legal and social aspects. The first stage involves analyzing the current state of the mining industry, including studying existing AI-technologies such as Cognitive Geologist and Cognitive Engineering systems, as well as identifying the constraints of traditional exploration and mining methods. The tools selected are content analysis of scientific literature relevant to AI in mineral mining and regulatory acts of Ukraine and Kazakhstan. A SWOT analysis was also conducted to identify the strengths/weaknesses of using AI in mining practice.

Next, a technological analysis of the capabilities of AI-systems is performed. Attention is paid to their application for predicting deposits, calculating mineral reserves, automating mining and managing production processes. Technological issues, including the "black box" phenomenon, are studied, and approaches to overcome it are developed using interpretability methods such as SHAP and LIME. The use of digital drilling, machine vision and other innovations that improve mining efficiency is also explored. At this stage, scenario modelling is performed using basic, optimistic and pessimistic scenarios. ROI-calculations, according to data from [18], [27], show that the benefit of reducing accidents, minus implementation costs in relation to total costs, can range from 20 to 30%.

The economic part of the research aims to model the effectiveness of using AI-technologies, including calculating operational cost savings, increasing productivity and improving environmental safety. The ROI and potential economic benefits are projected, such as reduced energy costs, fewer accidents and increased competitiveness of enterprises. In this case, the research is based on econometric modelling with regression on data [21], [31]. ROI is calculated using formula 1, adapted for conditions in Ukraine and Kazakhstan, where basic costs, such as for the Kazakhmys pilot project, are estimated at \$5-10 million. A SWOT analysis is also conducted for factors assessing digitalization opportunities and threats in the form of cyber risks.

Legal analysis within the framework of the research provides an examination of both the legal status of AI itself and the regulation of intellectual property (IP) rights to algorithms and data, as well as an analysis of liability for possible errors and accidents caused by the use of AI-technologies. Proposals are developed on insurance mechanisms and on the regulation of contractual relations between developers, technology users and insurance companies. At this stage, the methodological basis is a comparative legal analysis of the EU act [40] for high-risk mining in Ukraine and Kazakhstan based

on the criterion of the existence of AI norms. Using a formal legal method with regard to AI-liability, the provisions of the Mining Law of Ukraine, as well as such acts of the Republic of Kazakhstan as the Law “On Informatization” [3] and Government Resolution No. 846 were interpreted [41].

The social aspect of the research addresses the impact of AI-technology implementation on the labor market, including issues of worker retraining and possible social consequences. Recommendations are being developed for training specialists capable of combining knowledge in the AI-field and production processes in the field development. The analysis of staff needs covers surveys based on data in [20] and modelling, in which 15-25% of staff are sent for retraining. When calculating costs, it is necessary to take into account their quantity, average salary and training time.

At this stage, SWOT is conducted for social factors, where new jobs are strong and management resistance is weak.

Particular attention is paid to barriers to the implementation of AI-technologies, including economic, legal and staff challenges. For this purpose, based on content-analysis data, barriers are systematically categorized into three groups in a table. ROI calculations are performed to assess their overcoming, since lowering barriers increases ROI by 1.5-2.0 points.

The final stage of the research involves developing recommendations for creating a conceptual regulatory framework for AI-technology application in the mining industry, including operating standards, insurance mechanisms, and a roadmap for their implementation. The proposed measures will aim to achieve a balance between economic efficiency, social responsibility, environmental sustainability and European integration commitments. The research provides a synthesis of results, ranging from analysis to concept, a roadmap that is implemented at the stages of audit, pilot project and scaling with a timeframe until 2026 according to Government Resolution No. 320-r. The research sequence is presented schematically in Figure 1.

The proposed research methodology sequence provides a logical chain from data collection to model synthesis, minimizing subjectivity. Moreover, repeating the steps using the specified sources and tools confirms the reproducibility of this approach, since it yields similar results with an error of < 10% for ROI-models.

### 3. Results and discussion

#### 3.1. Regulation of the use of AI-technologies in economic sectors by the norms of international, European, Ukrainian and Kazakh AI-legislation

AI-technologies in the modern world are successfully used in everyday and professional life, as well as are used in such sectors as medicine, industry, agriculture, defence, education, etc. In general terms, AI-technologies are a type of information technology that has the following operating algorithm:

- 1) the software product receives a specific request;
- 2) data collection and processing;
- 3) issuance of a ready-made solution.

The latter is often perceived to be the result of a computer program possessing characteristics of intelligent behaviour and human thinking. Therefore, the legal regulation of AI-relations is sometimes reduced to an analogy of regulating the legal relations concerning the use of computer programs, that is, IP-relations.

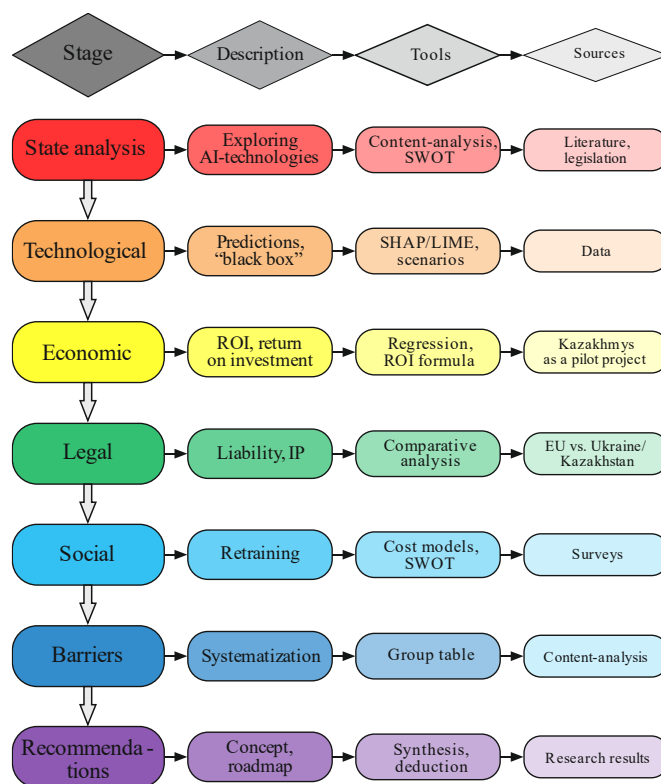


Figure 1. Sequence of research

Legal analysis as part of the research showed that the legal basis for the use of AI in the mining industry is far from being developed, since AI-legislation itself is not fully formed. However, an important aspect is the lack of certainty in the legal status of AI, which makes it difficult to assign liability for errors and accidents occurring during the operation of such systems. At present, legislative initiatives in this area are still insufficient to clearly define the rights and obligations of the parties, which creates a legal vacuum and additional risks for participants in AI- relations.

Adopted on 13.03.2024 by the European Parliament, AI-Regulation 2024/1689 (AI Act) introduces a broad definition of AI-systems, including all systems that can make decisions independently (with a certain level of autonomy) and demonstrate adaptability after implementation. These systems, with explicit or implicit goals, are capable of performing tasks that previously required human intervention, that is, analyzing the data received and generating results. The latter may take the form of predictions, content, recommendations or decisions that may influence the physical or virtual environment. This covers both highly specialized AI-models and general-purpose AI-systems (GPAI).

At the same time, the Blietchley Declaration of 2.11.2023 (adopted at the international forum on AI-safety, AI Safety Summit, Blietchley Declaration), states that AI itself poses a potentially catastrophic danger to humanity, therefore such fast-growing AI-technologies must comply with the principles of human-centredness, reliability, safety and responsibility in approaches to its use. In addition, the European AI Act is also designed to ensure safety and respect for citizens' rights when using AI. It is important to note that the AI Act specifies the subject structure of AI-relations to which its provisions apply. Unlike the European integration concept of "operators", this structure is proposed to be differentiated into three main groups, presented in Figure 2.

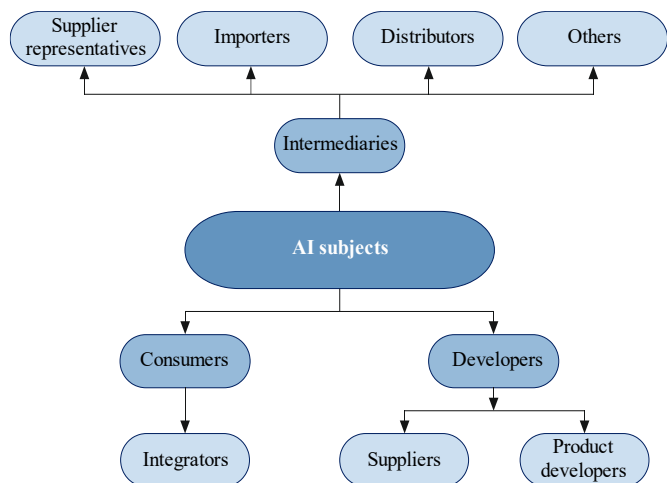


Figure 2. Subject structure of AI-relations

Figure 2 illustrates the hierarchy of participants in AI-relations, highlighting key roles in the chain from development to consumption. In this case, an analysis of their legal status demonstrates the potential existence of conflicts of interest between integrators and consumers in matters of legal liability, which requires appropriate legal clarification in the industry norms of Ukraine and Kazakhstan.

The International Guiding Principles for Organizations Developing Advanced AI-Systems and The International Code of Conduct for Organizations Developing Advanced AI Systems, adopted on 30.10.2023 as a result of the G7 Hiroshima AI Process, became extremely important acts at the international level, which, among other things, set out the basic principles of AI-relations.

For the purpose of further implementation into national legislation, it is proposed to systematize them in the form presented in Figure 3. It demonstrates the basic principles of AI-relations with a focus on a balance between humanity and safety. However, it should be noted that there is a potential correlation between safety priority and risk reduction in the mining process.

The above list of principles for the use of AI-technologies is not and cannot be exhaustive, as these technologies are

constantly evolving. The experience and practice of their use, as well as the constructive initiatives of participants in AI-relations, will undoubtedly contribute to the supplementation and editing of the fundamental principles of the AI-sphere.

Thus, all participants in AI-relations need to have both objective AI-rights and regulated subjective AI-rights and liabilities, which in aggregate would contribute to guaranteeing compliance with the law, minimizing possible legal risks. The lack of such a regulatory framework could lead to legal conflicts or slowdown in the development of AI-innovations. Currently, national AI-legislation is developed exclusively at the sub-legislative level (Concept for AI development in Ukraine, approved by Government Order of 02.12.2020 No. 1556-r), which accordingly constrains its development. The adoption of an AI-law or even an AI-code that not only complies with the AI Act but also develops it, will certainly take this legislative block to a qualitatively new level.

The classification of AI-risks proposed in the AI Act is based on the intended purpose of the AI-system, in accordance with current EU product safety legislation. This means that classification depends on the function performed by the AI-system, as well as on the specific purpose and means for which the system is used.

It appears that AI-risks can range from specific (general-purpose AI-systems) to high levels for mining industry enterprises. Requirements for relevant AI-systems are presented in Figure 4. It is proposed to enshrine them in the Concept for the Use of AI-Technologies in the Mining Industry.

The formulation of requirements for AI-systems used in the mining industry, shown in Figure 4, ensures their safe, controlled and transparent implementation into technological processes. It provides a framework for assessing and managing technological, environmental and social risks, as well as for assigning responsibility for algorithmic decisions. This helps to reduce the probability of accidents and minimize negative impacts on the environment. This ensures sustainable and regulatory-based use of AI in high-risk industrial environments. It should also be noted that general-purpose AI-systems are characterized by the following conditions.

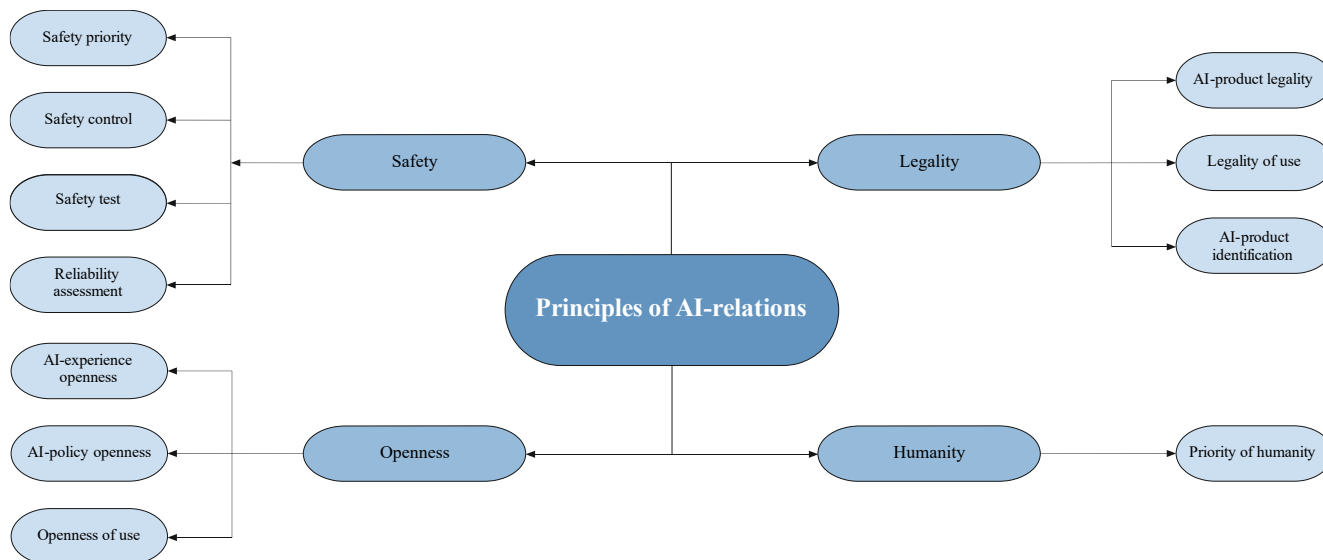


Figure 3. Principles of AI-relations

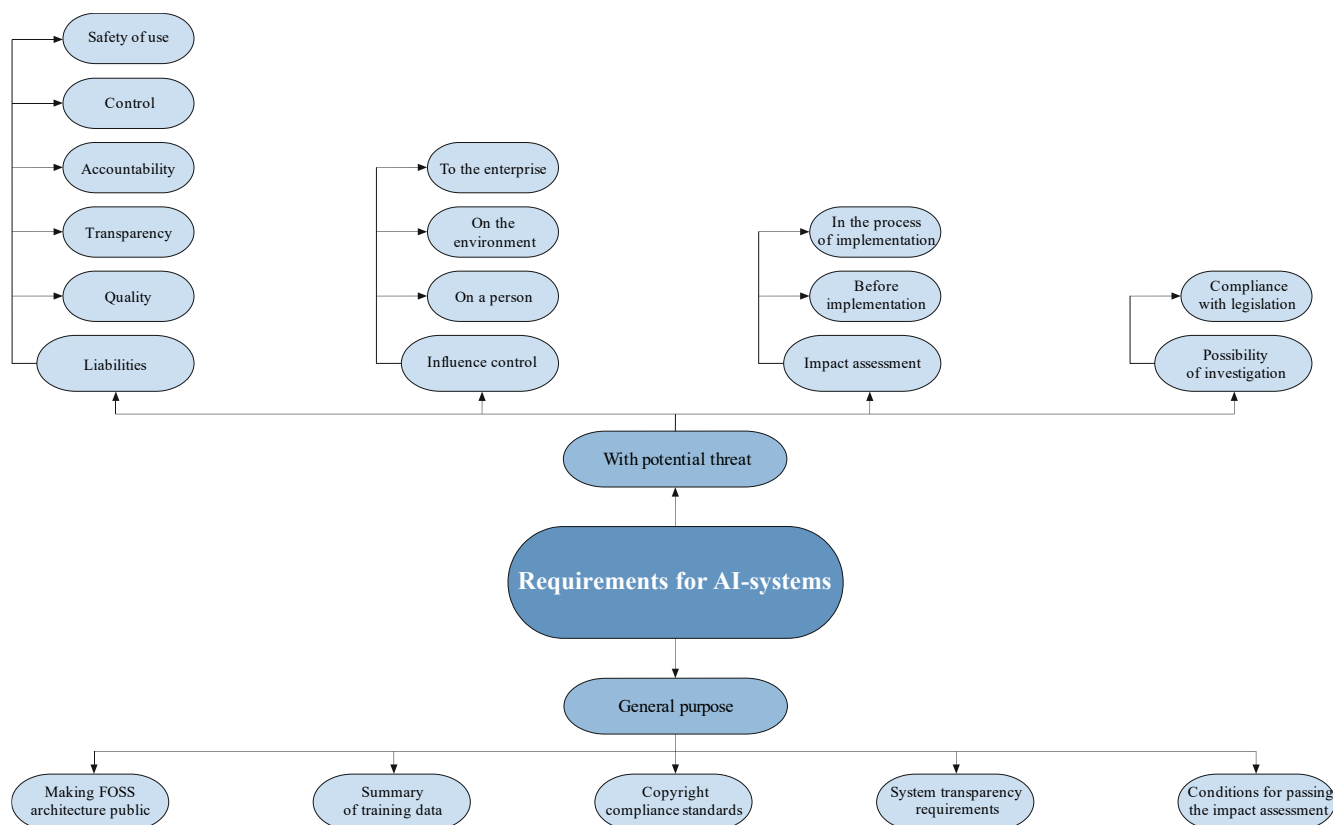


Figure 4. Requirements for AI-systems used in the mining industry

1. The AI-system is incorporated as a safety component in products subject to current EU product safety legislation, or is itself such a product.

2. The AI-system is intended for use in high-risk environments in accordance with the AI Act.

One of the key aspects that continues to be controversial among both scientists and practitioners is the issue of liability for errors made by AI-systems. Since such systems function as “black box” without the ability to explain the decision-making process, identifying the causes of errors becomes a difficult task. In the event of accidents or other adverse consequences, the question arises as to who should be held responsible – the developer, the system provider or the user themselves. Therefore, it is extremely important to identify the cause-and-effect relationship between the AI-system and the accident. To determine who is responsible for this situation, it is necessary to find out what caused it. These may include: defects in the AI-program that entail liability on the part of its developer; incorrect use of the AI-system by the user, entailing his/her liability; third-party interference in the AI-system (breakage, damage, modification), resulting in their liability.

Particular attention should be paid to IP-relations arising from the algorithms and data used in AI-systems. Difficulties arise because algorithms trained on large volumes of data often lack clear authorship, which complicates the determination of rights to such developments. This, in turn, may lead to legal conflicts between developers and users, especially in the case of claims of patent or copyright infringement.

For example, in the United Kingdom, legislation stipulates that a person who has taken measures to create an AI-object has ownership of it. According to the legislation of Ukraine (Law No. 2811-IX of 01.12.2022) [42], an author is an indi-

vidual who has created a work through his/her creative labour. The copyright holder has the right to use the work in any manner (or manners), as well as the exclusive right to permit or prohibit the use of the work by other persons.

To increase legal certainty and protect the interests of parties to AI-relations, it is also necessary to introduce insurance mechanisms that cover risks associated with AI-system errors and possible industrial accidents.

In addition, an important step in the legal sphere is the development of contractual relations between AI-technology developers, users and insurance companies. Contracts should clearly define the terms of liability, the obligations of the parties, and the mechanisms for compensation for damages. Contractual AI-relations should provide for the setting of clear standards and quality requirements for AI-systems, as well as the determination of legal consequences for users if the system operates inefficiently or leads to an emergency. It is also important to consider the specific nature of the mining industry, where the potential consequences of errors can be particularly significant.

Thus, legal regulation of the use of AI-technologies in the mining industry requires further refinement at the legislative, regulatory and local levels, which will help avoid legal ambiguities and enhance the legal security of all parties involved in the AI-process. An important factor here should be public-private AI-partnerships, the main goal of which should be to achieve a balance between the need to develop AI-innovations and the obligation to protect and guarantee human rights and freedoms from AI-risks. The mining industry, which is in a transitional phase, characterized on the one hand by the critical national importance of minerals and, on the other, by the European need to decarbonize the economy, must embark on a course of AI-transformation.

Moreover, already now mining industry enterprises that use, plan to use, or are interested in implementing AI-technologies should carry out a number of preparatory measures, which are presented in Figure 5. Figure shows the stages of AI-audit as a tool for assessing implemented tech-

nologies. Their consistent implementation, from inventory to monitoring, allows for the optimisation of AI-system launches at pilot facilities. The example of Kazakhmys enterprise, according to content-analysis, indicates a projected 25% reduction in the accident rate [5], [9].

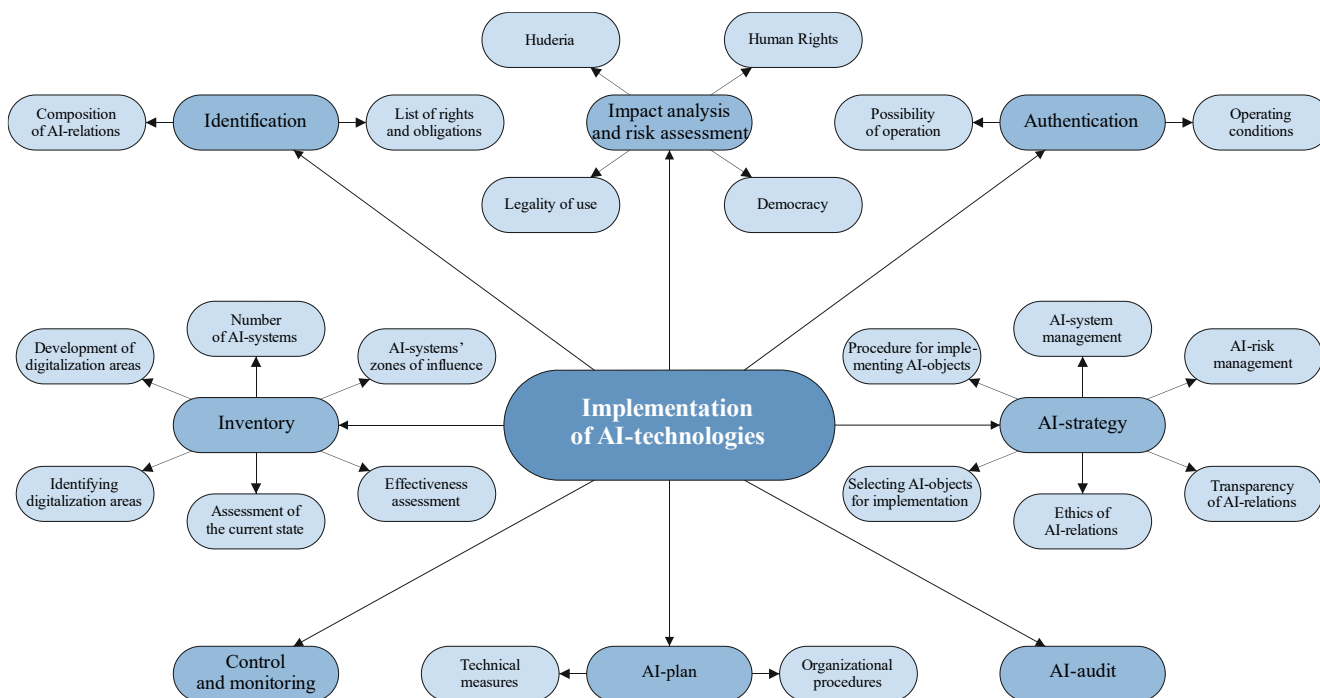


Figure 5. Preparatory measures for the implementation of AI-technologies

### 3.2. Comprehensive assessment of trends and factors accompanying the use of AI-technologies in mining enterprises

Any use of AI-systems in the mining industry should be based on the availability of key components that form the basis for their implementation. In addition to the regulatory framework for the digital environment discussed above, another important component is the information infrastructure, which ensures the efficient processing, storage and transfer of large volumes of data. They form the basis for the operation of AI-technologies, and their quality and availability are crucial. Alongside this, a developed information security infrastructure is needed to protect against cyber threats, especially those that are relevant for critical production processes.

Another critical factor is the introduction of digital technologies, which open up new opportunities for automation, remote control and monitoring. Effective integration of these technologies requires digital governance at the national, industry, regional and individual enterprise levels to ensure coordination and synchronization of efforts among all participants in the process.

It is worth highlighting the need for staffing in the digital economy. The success of AI-system implementation, as well as their further maintenance and development, depends on qualified specialists. Staff training should cover both technical aspects and the economic-legal consequences of implementing AI-technologies. In particular, the Law of Ukraine “On Stimulating the Development of the Digital Economy in Ukraine” (dated 15.07.2021, No. 1667-IX) [43] defines the organizational, legal and financial foundations for the functioning of the Diya City legal regime, introduced

with the aim of stimulating the development of the digital economy in Ukraine by creating favourable conditions for conducting innovative business, developing digital infrastructure, attracting investment, as well as talented specialists.

During the study of the application of AI-technologies in the mining industry, several key areas will be analysed, aimed at improving exploration processes, mining automation, industrial, energy and environmental safety, as well as management of production processes and resources. In general terms, the system of such trends and factors is presented in Figure 6.

Figure 6 reveals the multi-level structure of AI-technology application in mining enterprises. The synergistic effect between the economic and social spheres in the context of technological process automation contributes to increased productivity. However, it also strengthens the need for legal regulation of risk balance relations, as reflected in the models [4].

#### 3.2.1. Production factors and trends

One example of applying AI-technologies is the use of AI-system Cognitive Geologist, which is used to search for and assess mineral deposits. This system analyzes geological data and accelerates the assessment process, reducing data processing time from several months to several weeks. As a result, the assessment of geological objects becomes more accurate and faster. For example, the traditional process of assessing the profitability of field development can take up to two years, whereas using this AI-system, the procedure is completed twice as fast. In addition, the Cognitive Geologist system can significantly improve the process of prospecting for deposits by analyzing large volumes of data, including geophysical, geochemical and seismic surveys.

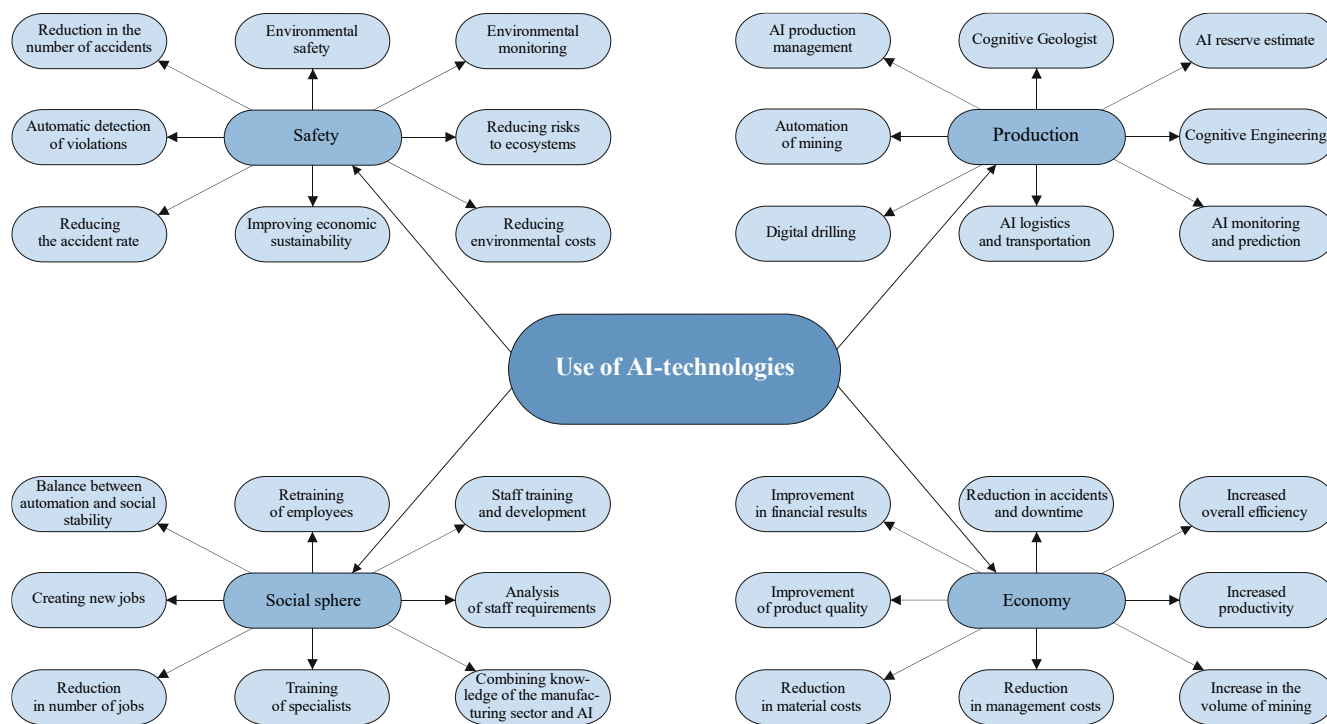


Figure 6. System of trends and factors accompanying the use of AI-technologies in mining enterprises

This, in turn, allows for faster and more accurate prediction of deposits, which is a significant step towards improving exploration efficiency and reducing costs.

AI-systems for calculating mineral reserves also significantly improve the geological-exploration process, as modern systems are capable of automatically processing data obtained during geophysical surveys and drilling [44]. This accelerates the process and increases the accuracy of calculations, which significantly saves time and resources traditionally spent on such work. Such AI-geosystems can take into account complex geological factors, such as variations in mineral distribution and rock porosity, which increases the accuracy of reserve estimates. Another example is the Cognitive Engineering AI-system, which, using multi-factor models, proposes optimal deposit development schemes. This system is capable of taking into account a variety of parameters, such as geological conditions, economic feasibility, and offers the best solutions for rational use.

AI is also actively used in monitoring and prediction systems in mining operations. For example, AI is used to monitor the condition of equipment so that potential faults can be quickly identified and accidents prevented. Systems can predict potential failures by using data from sensors and analyzing current machine operation parameters. The implementation of such AI-systems, for example, can analyze the state of conveyors/crushers and warn the operator of the need for their repair [45]. Mining industries also use systems to optimize logistics and transportation of minerals. For example, AI-systems can predict transportation resource requirements, improve delivery routes and minimize fuel costs. The use of unmanned aerial vehicles (UAVs) in field development is also effective: they are used to scan terrain, create 3D-models and assess the state of open quarries [46].

In the field of data processing, AI-systems are used to analyze water/reagent consumption and raw material quality, which helps to optimize mining. For example, such a system can provide “cues” to operators on how to improve produc-

tion parameters and reduce costs. The implementation of AI-solutions has already yielded significant results in some enterprises, where water/reagent consumption has been reduced by 15-20% [47].

Innovations such as digital drilling and machine vision also play an important role in improving the efficiency of mineral mining. Digital drilling enables real-time control of the drilling process and monitoring of the condition of drilling tools, while machine vision is used to monitor compliance with safety standards and analyze the quality of raw materials [48]. These AI-technologies improve predictive accuracy and workplace safety [49].

In addition, AI-systems are actively used to automate mining processes. As part of the Smart Mining concept, AI-systems can optimise the operation of drilling rigs, conveyors and crushers, resulting in significantly increased productivity and reduced need for human intervention. Such systems are also used to monitor equipment, enabling the prediction of breakdowns and emergencies, while minimizing downtime and repair costs. In this case, it can be argued that in the mining industry, the development of this concept is of a combined nature, “from part to whole”. The latter manifests itself in the possibility of applying both mono- and poly- AI-technologies. Moreover, the choice of option is determined not only by financial aspect, but also by production capacity and necessity.

AI-systems in the field of production process management help to optimize the consumption of resources such as water, reagents and energy, thereby reducing operating costs. All operating parameters of a mining enterprise can be monitored in real time, allowing for prompt decisions to be made to improve the efficiency of mining operations.

### 3.2.2. Economic factors

An analysis of the economic efficiency of implementing AI-technologies in the mining industry has shown that the use of AI-systems contributes to a significant reduction in operating costs [50]. Especially when it comes to optimizing

diagnostics and equipment repair processes. The implementation of AI-systems to predict breakdowns and optimize production processes has significantly reduced unforeseen costs associated with accidents and downtime, thereby increasing overall operational efficiency.

The use of AI-technologies to automate mineral mining and improve logistics has resulted in increased productivity. Accelerating processes, reducing data processing time and improving the accuracy of operations have made it possible to increase overall mining output and reduce process management costs. This has also contributed to a reduction in energy and material costs, as AI-systems enabled more accurate calculation and use of resources.

From an investment perspective, the payback calculation showed that the implementation of AI-systems can be profitable even in the short term, with a high return on investment. This is particularly important for mining enterprises focused on long-term sustainability and competitiveness. Improved product quality and increased operational efficiency have enabled such mining enterprises to gain a more advantageous position in the market, which also affects their financial results.

### 3.2.3. Social factors

The social aspect of the research showed that the implementation of AI-technologies in the mining industry will inevitably affect the labour market, creating both opportunities and challenges. One of the main issues is the need for staff retraining, which is linked to changes in production processes and increased demands on technical skills. Traditional working professions, such as mining machine operators or geologists, may face the replacement of some of their functions with automated AI-systems, which will require a new approach to staff training and development [51].

An important element of the research is the analysis of the needs for new professional skills that will be in demand due to the development of AI-technologies. Specialists capable of combining knowledge in the AI-field and in production processes will become key figures in ensuring the effective application of new AI-technologies in the mining industry. This includes training specialists in the MO-field, big data processing, as well as those who will work with new types of equipment and software used in mineral mining.

The research also addressed the potential social consequences of AI-technology implementation. On the one hand, process automation may lead to a reduction in the number of jobs, which will create challenges for regions that are heavily dependent on the mining industry. On the other hand, increased productivity and reduced operating costs can lead to economic growth and the creation of new jobs, especially in the field of development, maintenance and operation of AI-systems. It will be important to consider the balance between process automation and the need to support social stability in industrial regions.

### 3.2.4. Safety factors

One of the key results of the implementation of AI-technologies is improved environmental safety. The use of AI-systems to monitor the state of the environment and control emissions will significantly reduce the environmental footprint of mining enterprises. This should reduce risks to ecosystems, as well as the costs of complying with environmental norms and standards.

In addition, reducing the number of emergencies and minimizing associated costs will be an important factor in improving the overall economic sustainability of enterprises. Reducing accidents will not only reduce operational costs, but also improve occupational safety, which is also important for economic performance.

AI machine vision technology can be used to improve industrial safety by monitoring the use of personal protective equipment by workers. This system analyzes video and images from surveillance cameras, automatically detecting violations and warning managers when employees are not wearing protective equipment [17], [52]. This helps to significantly reduce the number of accidents in the workplace.

### 3.3. Analysis of existing barriers and possible consequences of AI-technology use in mining enterprises

Long-term results, including improved safety, environmental sustainability and productivity, make the implementation of AI-technologies highly promising for mining enterprises. However, despite the numerous economic benefits of using AI-technologies in the mining industry, some challenges remain problematic. In general terms, the system of barriers and possible consequences of the use of AI-technologies in mining enterprises is presented in Figure 7.

Figure 7 provides a branching classification of barriers to AI implementation. In conclusion, it can be argued that in Kazakhstan, due to the lack of appropriate norms in the Law on Subsoil, there is a dominance of legal barriers, which significantly delays the return on investment. At the same time, economic factors prevail in Ukraine, driven by the need for targeted investments.

In particular, the implementation of AI-systems in mining enterprises requires significant initial investment, as well as competent training and education of personnel. The latter aspect is conditioned by the negative perception of innovations by management entities, caused by the risk of personal liability for the introduction and implementation of AI-technologies, as well as a lack of understanding of the principles of AI-systems in the field of geotechnologies and fears of adverse consequences from their use, including unjustified economic losses.

That is, the staff barrier when using AI-technologies, mainly consists of the need for enterprise employees to obtain additional AI-education, since a balance with the profile (geological, mining) education is necessary, due to the lack of understanding of production processes by a specialist with AI-training. The economic barrier can be explained by the existence of economic risk for a legal entity implementing AI-technologies in the form of property losses caused by possible industrial accidents. The same can be said about safety barrier when, for example, equipment used in the mining industry and managed by an AI-system is not included in the list of high-risk facilities. In such a situation, there is a real possibility that this equipment could cause harm to the life and health of employees of mining enterprises, which leads to problems with concluding insurance contracts for the damage caused. Furthermore, the possibility of imposing precedent-setting legal liability on the mining enterprise and/or its officials in the event of an accident should not be excluded.

One component of the social barrier is the threat of job reduction in mining enterprises caused by the implementation of AI-systems and, as a result, the need to invest in the creation of new jobs.

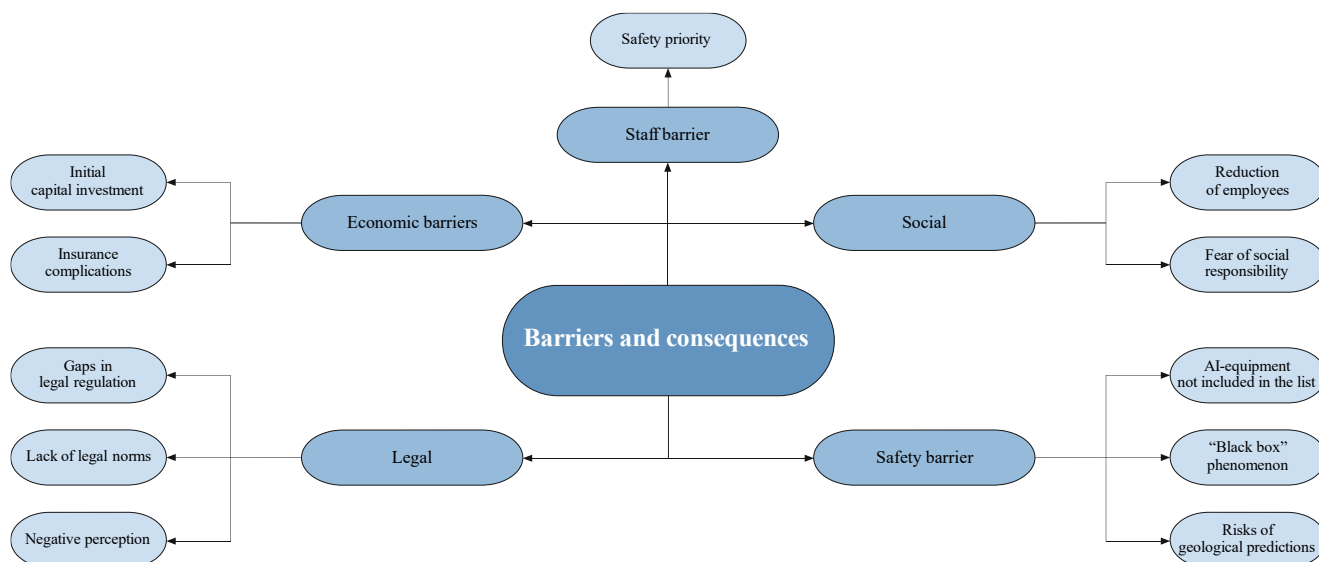


Figure 7. System of barriers accompanying the use of AI-technologies in mining enterprises

Gaps in the legal regulation of using AI-systems, the lack of legal norms setting the status of AI itself, governing the rights and obligations of subjects of legal AI-relations, as well as the powers of supervisory authorities, are at the core of the legal barrier. Indeed, legal uncertainty gives rise, among other things, to the forced acceptance of additional risks from the operation of AI-systems. For example, the possibility of creating an industrial emergency due to an error made by such a system. Against this background, the lack of legal security makes the scope of contractual relations between AI-developers and mining entities, as well as between mining entities and insurance entity, problematic.

The most unpredictable consequences of using these systems are related to the so-called “black box” phenomenon, when AI-systems cannot explain how they arrive at their decisions. This creates risks, especially in the area of deposit prediction or reserve estimation, where errors can result in significant financial losses. To overcome this problem, methods for explaining how AI-systems operate must be developed in order to increase the transparency of their decisions.

### 3.4. Conceptual recommendations for the creation of AI-enterprises

It is proposed that the economic-legal Concept for the use of AI-technologies in the mining industry be based on the above-mentioned national AI-Concept. The framework of the industry Concept is presented in Figure 8, where illustrates the binary structure of relationship groups in the AI-Concept. Its distinctive peculiarity is the priority given to the norms of the special section to ensure state regulation, which makes the model innovative compared to [13]. Furthermore, for Ukraine, integration with post-war transformation will increase the ROI.

The conceptual framework should be specified at the level of the industry AI-Strategy, where it is necessary to consider individual areas of AI-enterprise, including Smart Mining and E-engineering. In particular, the possibility and expediency of using AI-systems in the areas are given in Figure 9, where shows a visual AI-impact scheme. This system provides for a correlation between risk assessment and environmental sustainability, with potential emission reductions through monitoring.

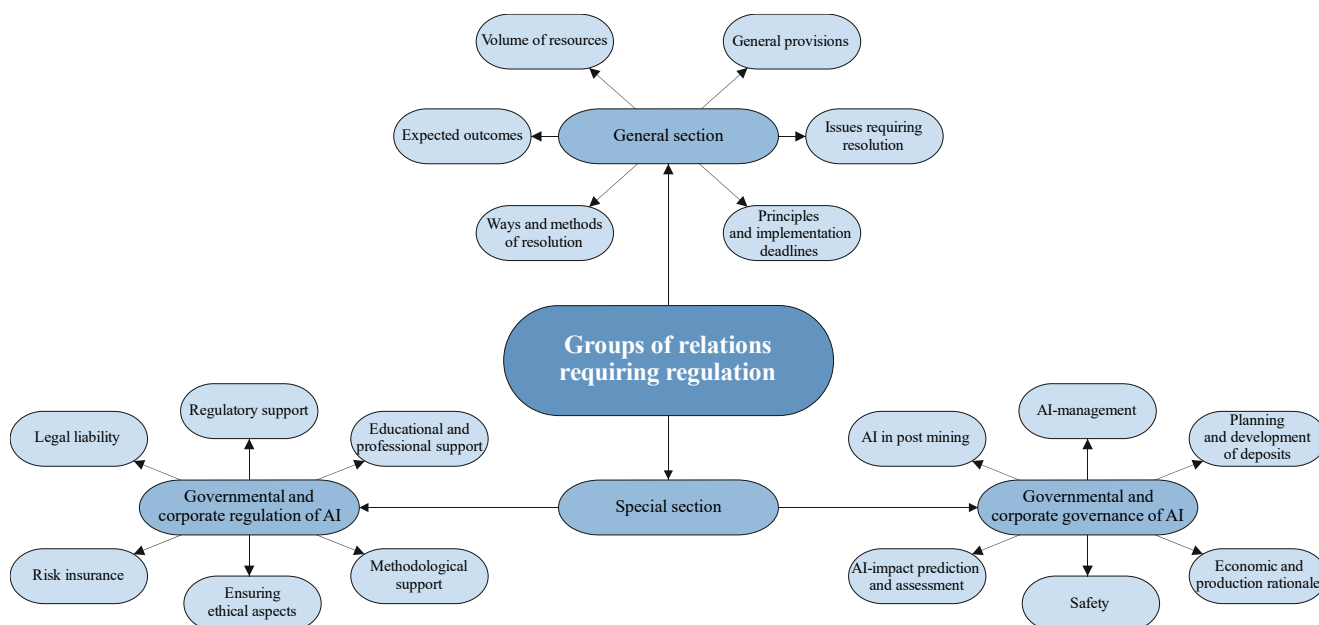


Figure 8. Framework of the AI-Concept for the mining industry

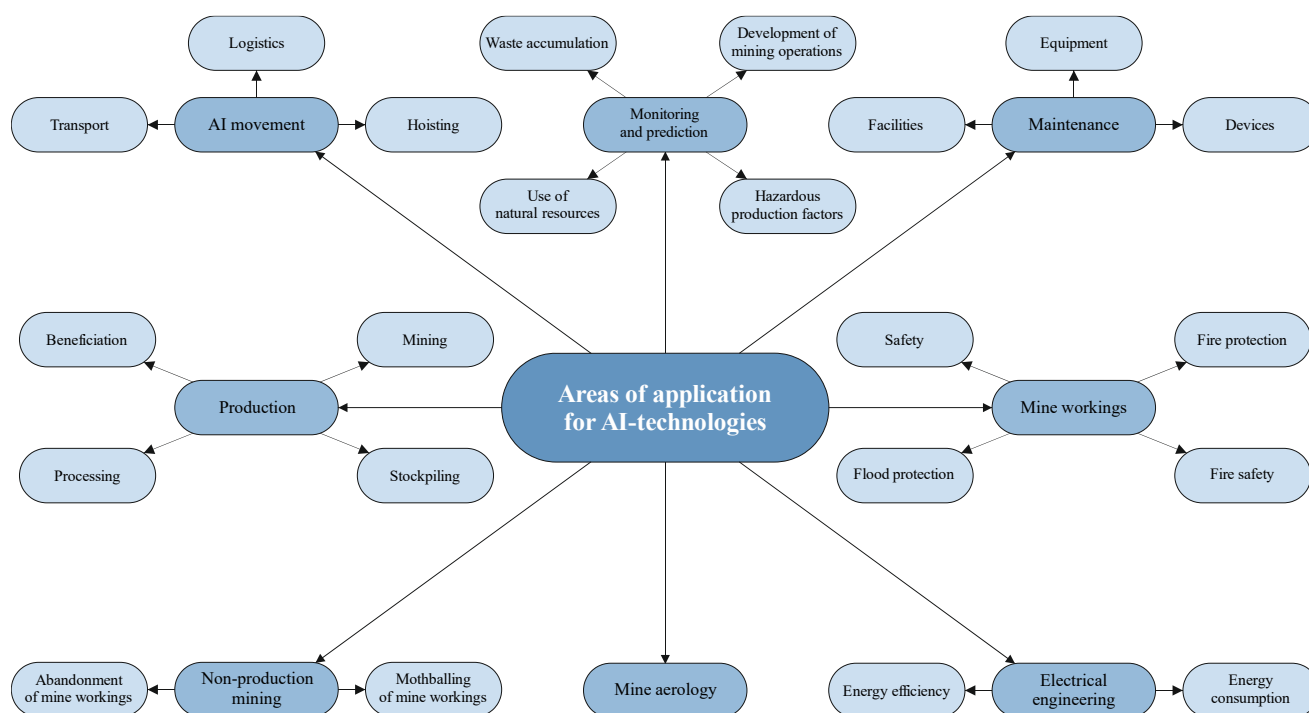


Figure 9. Areas of application for AI-technologies in mining enterprise

At the same time, its full re-creation is linked to the need to adapt EU standards in the legislation of Ukraine and the Republic of Kazakhstan.

It should be noted that the integration of AI-systems into the mining industry opens up new opportunities for its transformation, but at the same time poses a number of technical, economic and legal challenges. Thus, in the direction of Smart Mining, the key aspects are the automation of mining processes, real-time monitoring of the state of enterprises, and ensuring the safety of workers through the implementation of AI-systems. The use of robots, drones and smart sensors reduces accident risks while also requiring a regulation of issues of liability for technical failures and damage caused by such systems.

E-engineering involves the use of AI for designing and optimizing engineering solutions. This reduces the time needed to develop new technologies and processes. However, it is important to consider AI-protection issues in algorithms and technical developments, as well as in possible legal conflicts between project participants.

Thus, based on the conducted analysis, conceptual recommendations have been developed that can be used in the process of creating an AI-enterprise and its individual elements. This refers to the possibility of phased implementation of AI-systems at individual facilities of mining (processing) enterprise [53]. This approach seems to be the most appropriate in the context of limited investment resources. When selecting an object for digitalization, it is also possible to use the options proposed by the AI-management system, with their subsequent assessment by the enterprise management. These objects may be material (mineral reserves and resources, mining allotment or its part, mining horizon, site, mine working, electricity, transport, air, water, waste), operational (management, mining, storage, processing, beneficiation, monitoring, prediction, repair, disposal, abandonment) or information resources directly and/or indirectly related to the operation of a mining enterprise, its results and consequences, as well as their various combinations.

The analysis of barriers to the implementation of AI-technologies in the mining industry was conducted based on a content-analysis of more than 50+ regulatory acts (Ukraine: Mining Law [2], CMU Order No. 320-r [1]; Kazakhstan: Law “On Informatization” [3]; EU: AI Act) and literature [4], [13]. Three groups of barriers have been identified: economic (capital investment, return on investment), legal (gaps in liability, “black box”) and social (staff shortage). Support factors are classified according to their areas of impact (technological, organizational). SWOT scenario modelling showed that barriers reduce ROI by 20-30% in the first 2 years, but are compensated for by legal adaptation (risk insurance increases ROI to 1.5-2.0). For the Republic of Kazakhstan – adaptation to the Concept of Information and Communication Technologies, ICT Concept [54], and Kazakhmys practice [9], with ROI > 1.5 due to standards [10].

An example of economic barriers can be seen in the situation at the Kazakhmys enterprise in Kazakhstan. Their dominance, according to the Concept of Digital Transformation of the Republic of Kazakhstan [4], is confirmed by data on investments in AI > \$5 million per pilot project with a pay-back period of > 2 years. In Ukraine, post-war transformation is exacerbating them due to infrastructure losses. Legal barriers are related to the lack of interpretability standards (SHAP-methods are not mandatory); social barriers are related to the need to retrain 15-25% of staff (analysis [6], [55]). Factors: positive (automation reduces accidents by 25%, [3], [56]); negative (cyber risks [37], [57]). The systematization of barriers and factors is presented in Table 1 and Table 2.

The proposed structure provides a balance of risks and benefits, confirming the applicability of the AI-Concept model developed by the authors. A promising area is the creation of e-products, where the use of AI-technologies allows the creation of a product with added value, ensuring its competitiveness in global markets. For example, the production of commercial products with predictable characteristics could become a promising area of development in the mining industry.

**Table 1. Systematization of barriers**

Barrier group	Description	Examples (Ukraine/Kazakhstan)	Impact on ROI	Mitigation (recommendation)
Economic	High capital investment; long payback period	Investments in digital drilling (> 2 years, Kazakhmys); energy costs in post-war mines	Reduction by 20-30%	ROI-modeling; grants (the Republic of Kazakhstan until 2025)
Legal	Gaps in liability; “black box”; lack of insurance	Lack of AI norms in the Law on Subsoil of the Republic of Kazakhstan; liability for errors in the Mining Law of Ukraine. Law on AI [39]; gaps in liability for [54], [58]	Delay in implementation by 1-2 years	Impact assessment (SHAP); IP agreements
Social	Staff shortage; resistance to change	Retraining of 15-25% of miners (Dnipropetrovsk Oblast); fear of job reductions in the Republic of Kazakhstan	10-15% productivity reduction	Training programs; automation balance

**Table 2. Systematization of factors**

Group of factors	Description	Examples	Effect
Technological	Data quality; integration with legacy-systems	Monitoring in the Cognitive Geologist	+ 25% prediction accuracy
Organizational	Risk management; AI-audit	Roadmap (testing → monitoring)	20% reduction in accidents

Thus, the application of AI-technologies in the geological and mining industries can ultimately become a driver of economic growth, increased efficiency and process safety. However, this will require not only investment in these technologies, but also the development of a flexible and transparent regulatory framework that will promote trust in AI both in business and in society.

### 3.5. Comparison of the obtained results with previously conducted studies

Research focused on the technological and production efficiency of AI-solutions is predominant in modern scientific literature on the application of artificial intelligence technologies to the mining industry. At the same time, economic and legal aspects are generally treated in a fragmented manner, without forming a holistic institutional model for their implementation.

The AI-Concept model for the mining industry proposed in this paper expands on the approaches outlined in [18], where the emphasis is on the economic barriers to AI implementation (financing, staff qualification) without detailed integration of legal aspects. Our model complements this by incorporating Kazakhstan’s normative and legal regulation (Law of the Republic of Kazakhstan “On Informatization” No. 418-V, 2015 [3]), including mechanisms for liability for “black box” and risk insurance, which increases applicability in the post-Soviet context (ROI-assessment shows a 15-20% reduction in costs due to legal transparency, as opposed to general recommendations [18]).

Compared to [27], which focuses on AI barriers in the oil and gas industry (structural “digital bottlenecks”, infrastructure modernization) without considering post-war transformation, our research integrates these elements into a model for solid minerals. The novelty consists in adapting to the conditions in Ukraine (post-war transformation of enterprises under CMU Order No. 320-r, 2024 [1]) and Kazakhstan (Kazakhmys as a pilot project [5]), where SWOT scenarios for staff retraining (15-25% of employees) are added, which are absent in [13]. This provides a balance of economic efficiency (a 20-30% reduction in accidents) and legal sustainability, as confirmed by content-analysis of 50+ acts.

Unlike [21], where machine learning is used to rock modeling with reference to legal aspects but without a comprehensive concept, our model synthesizes this into a framework with AI-system requirements (impact assessment via SHAP), increasing reproducibility. The comparison highlights the scientific novelty: the first integrated economic and legal framework for mining that takes into account the binary context of Ukraine and Kazakhstan, with quantitative metrics (ROI > 1.5 over a 2-year horizon) not presented in similar publications.

In a number of studies devoted to the oil and gas sector, AI is primarily interpreted as a tool for improving operational efficiency and risk management. Thus, the results presented in [59] demonstrate that the use of generative AI and machine learning algorithms can optimize risk profiles and improve productivity at various stages of the value chain. The economic assessment is based on an analysis of the impact of AI on performance indicators, while issues relating to the legal status of AI-systems, the distribution of liability and regulatory requirements for data remain outside the scope of the study. In contrast to this approach, this paper links the economic effects of AI implementation to the formalization of AI-relation subjects and the impact assessment procedure, which allows economic efficiency to be considered inextricably linked to legal admissibility of AI use.

A similar focus on economic indicators is characteristic of energy transition research in the oil and gas industry. In [60], it is shown that AI-technologies contribute to reducing costs and emissions by optimizing multi-energy systems and predicting demand. The economic effect is considered in the context of the “dual-carbon” strategy, but the legal mechanisms for fixing these effects (data requirements, intellectual property, operator liability) are not analyzed. The paper addresses this gap by incorporating legal requirements for AI-systems and integrating them into national digitalization strategies, thus viewing cost and emissions reductions as the result of an institutionally enshrined process.

Overview studies of the oil and gas industry based on bibliometric analysis also note the growing importance of AI. The findings presented in [61] demonstrate the significant impact of AI on the efficiency and safety of production operations, as well as its role in achieving ESG-goals. At the same time, economic and legal issues are limited to general refe-

rences to the need to comply with regulatory requirements. In contrast, the above-mentioned paper specifies the economic and legal parameters of AI implementation by formalizing the stages of AI-enterprise creation, calculating payback periods, and defining insurance and contractual regulation mechanisms.

Research focused on the practices of oil and gas companies often identifies barriers to AI implementation as a factor affecting economic efficiency. In [62], the main focus is on data quality issues, integration with legacy systems, and infrastructure constraints that increase costs and reduce the expected impact of digitalization. These findings are further developed in the analyzed work, where the specified barriers are interpreted as a consequence of not only technological but also legal gaps, in particular the lack of data standards and regulatory recognition of decisions made by AI-systems, which directly affects investment risks and payback periods.

In the mining industry, a significant number of publications are devoted to social and organizational aspects of AI implementation. Thus, the findings presented in [63] systematize the barriers to the implementation of intelligent systems within the framework of technological, organizational and environmental factors, emphasizing the need for change management. In the analyzed paper, these provisions are further developed by including legal instruments for regulation and economic assessment of the consequences of automation, which makes it possible to link the identified barriers with specific mechanisms for overcoming them.

Studies on digitalization of the mining industry emphasize the role of AI in improving sustainability and safety. The findings presented in [64] indicate regulatory uncertainty as a key constraint on AI implementation. In the study under review, this uncertainty is overcome through the formalization of AI-system requirements and liability mechanisms, including the use of interpretable models and post-hoc analysis, which reduces both legal and economic risks.

A similar issue is raised in [65], where emphasis is placed on the need to consider the social and regulatory consequences of automation. However, these aspects are general in nature. In the analyzed paper, they are specified through taking into account the costs of retraining staff, assessing long-term payback, and including these factors in the economic and legal model for AI implementation.

The prospects for AI in the mining industry, as outlined in [66], are linked to increased autonomy and environmental responsibility, but are accompanied by risks of social tension. In this paper, these risks are interpreted in the context of just transformation of mining regions and are supplemented with legal and economic instruments to mitigate negative effects, which broadens the scope of analysis compared to existing approaches.

Cross-industry reviews, such as in [67], demonstrate the versatility of AI-solutions for the mining and processing industries and their impact on compliance with ESG-requirements. However, the legal and economic mechanisms for implementing AI in these areas are not specified in detail. The approach presented in the paper eliminates this deficiency by institutionally elaborating the role of regulators, operators, and developers of AI-systems.

Finally, strategic studies of the oil and gas industry, as outlined in [68], highlight the need for data standardization and platform cooperation to improve the effectiveness of AI applications. In this paper, these provisions are supplemented

by an analysis of the legal conditions for implementing such strategies in national jurisdictions, which makes it possible to link technological development with economic predictability and regulatory certainty.

Taken together, the studies reviewed confirm the high importance of AI for improving the efficiency and sustainability of the mining industry, but they focus primarily on technological and organizational aspects. The presented findings expand this body of scientific knowledge through a systematic economic and legal interpretation of AI implementation, ensuring the reproducibility, regulatory compatibility, and practical applicability of the proposed solutions in the context of real industry and institutional constraints.

#### 4. Conclusions

As part of this research, an economic and legal assessment, as well as analysis of the application of AI-technologies in mineral resource mining was conducted. As a result of the research, an integrated AI-Concept model for the mining industry has been developed, structured into general and specific parts. It is based on the systematization of individual legislative acts of Ukraine, Kazakhstan and the EU in the AI-field, which made it possible to determine the subject structure and principles inherent in AI-relations that were not previously integrated into the industry context.

Requirements for AI-system elements in mining facilities with potential threat and general-purpose facilities have been formulated. This made it possible to differentiate between the conditions for mandatory and optional assessment of AI-technologies in the process of their inventory, authentication, monitoring, copyright compliance, and training. A set of preparatory measures is also proposed, including an AI-audit, ROI-modelling, SWOT-analysis and a roadmap for phased implementation.

Economic, legal and social barriers to the implementation of AI-technologies in mining enterprises have been systematized. Key obstacles include the long payback period for capital investments, legal gaps in liability for the “black box” of AI-systems, and a staff shortage requiring the retraining of 15-25% of personnel. The analysis made it possible to conclude that in Kazakhstan such barriers are exacerbated by the lack of industry-specific regulations in the Law on Subsoil, while in Ukraine they are linked to post-war transformation factors.

Conceptual recommendations have been developed for the creation of AI-enterprises, based on an approach of integrating Cognitive Geologist and digital drilling with legal support for contractual and insurance mechanisms. An economic content assessment of individual AI-systems confirms a 15-25% reduction in costs through automation. In the legal aspect, based on SHAP-methods, a balance of liability can be found through post-hoc interpretability of the proposed models.

The results obtained broaden the approaches to understanding the essence of barriers in the process of industry adaptation of AI-technologies in mineral mining. The proposed integrated model has a Kazakh-Ukrainian context, to which European-AI standards can be adapted, allowing gaps in the sustainable development of the mining industry to be eliminated. The research purpose was achieved by developing a comprehensive economic and legal concept, which is reproduced through stages of data collection, SWOT-analysis and synthesis of results.

## Author contributions

Conceptualization: RK, OP; Formal analysis: OP, LN; Funding acquisition: BR; Investigation: RK, OP, LN; Methodology: BR, VK; Project administration: BR, SH; Supervision: BR, SH; Validation: SH, AS; Visualization: VK, AS; Writing – original draft: RK, LN; Writing – review & editing: VK, AS. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of interests

The authors declare no conflict of interest.

## Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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## Технології штучного інтелекту у видобутку корисних копалин: економіко-правова оцінка та аналіз

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**Мета.** Дослідження та розробка економіко-правової концепції використання технологій штучного інтелекту (ШІ) при видобутку корисних копалин на основі аналізу досвіду їх застосування у світовій гірничодобувній практиці, включаючи оцінку правового та технологічного забезпечення.

**Методика.** Дослідження проведено з використанням оглядового економіко-правового підходу, що полягає в оцінці та аналізі симбіозу позитивних і негативних аспектів впровадження ШІ-технологій на підприємствах видобувної промисловості. У рамках представленої статті проведено огляд законодавства з використанням процесів правового аналізу, включаючи порівняльний, системний та формально-юридичний методи, що забезпечують регулювання ШІ-відносин. З метою дослідження ключових аспектів, що супроводжують процеси використання ШІ-технологій на підприємствах видобувної промисловості, було проведено систематизацію європейських, українських та казахських нормативно-правових актів, а також економетричне моделювання ефективності застосування ШІ-технологій для оцінки експлуатаційних витрат.

**Результати.** Визначено суб'єктний склад та принципи ШІ-відносин, а також сфери застосування ШІ-технологій на видобувних підприємствах, які необхідно враховувати під час їх впровадження у видобувній промисловості. Сформульовано вимоги до ШІ-систем, які використовуються та/або можуть бути використані у видобувній промисловості. Систематизовано та проаналізовано групу бар'єрів, що супроводжують використання ШІ-технологій на видобувних підприємствах. Розроблено авторську структуру ШІ-концепції для видобувної промисловості. Запропоновано комплекс підготовчих заходів щодо впровадження ШІ-технологій, розглянуто напрями та чинники, що супроводжують їхнє використання на підприємствах видобувної промисловості.

**Наукова новизна.** Розроблено модель ШІ-концепції у видобувній промисловості, а також концептуальні рекомендації щодо створення ШІ-підприємств, які у представленому, інтегрованому вигляді не знайшли свого відображення у законодавстві та науковій літературі провідних видобувних країн світу.

**Практична значимість.** Результати дослідження можуть бути використані в процесі розвитку економіко-правових відносин у видобувній промисловості. Рекомендації концептуального характеру стануть у нагоді під час поетапного створення видобувних ШІ-підприємств. Їхня реалізація дозволить вирішити гострі соціально-економічні, інвестиційні та екологічні питання в умовах справедливої трансформації видобувних регіонів.

**Ключові слова:** ШІ-технології, видобуток, економічна оцінка, правове регулювання, галузева реформа, видобувна промисловість

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