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АКАДЕМИЯСЫ» РҚБ

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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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DETERMINANTS FOR ASSESSING THE ENERGY EFFICIENCY OF A COAL MINING ENTERPRISE

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Abstract. The article is devoted to consideration of issues related to assessing the energy efficiency of a coal mining enterprise. Coal mining enterprises are characterized by a large volume of energy-intensive ore mining operations. The article presents possible ways of energy saving in the mining industry. During the research, a system of energy efficiency indicators for coal mining enterprises is presented. The purpose of the article is to analyze the determinants of assessing the energy efficiency of a coal mining enterprise. Existing methods and approaches for assessing the energy efficiency of industrial enterprises as a whole are considered. The author's approach to formalizing a system of energy efficiency indicators for coal mining enterprises is proposed. The importance of an energy audit for assessing energy efficiency is outlined and its stages are highlighted. The factors influencing

the energy efficiency of a coal mining enterprise are also systematized, and the barriers that impede the practical implementation of energy efficiency measures are analyzed. Measures are outlined that will help improve the energy efficiency of mines.

Keywords: energy efficiency, assessment, mine, resources, costs, mining industry, formalization of the system of indicators, barriers

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КӨМІР ӨНДІРУШІ КӘСІПОРЫННЫҢ ЭНЕРГИЯ ТИІМДІЛІГІН БАҒАЛАУ ДЕТЕРМИНАНТТАРЫ

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Аннотация. Мақала көмір өндіруші кәсіпорынның энергия тиімділігін бағалауға қатысты мәселелерді қарастыруға арналған. Көмір өндіруші кәсіпорындар энергияны көп қажет ететін кен өндіру операцияларының үлкен көлемімен сипатталады. Мақалада тау-кен өнеркәсібіндегі энергияны үнемдеудің ықтимал жолдары берілген. Зерттеу барысында көмір өндіруші кәсіпорындардың энергия тиімділігі көрсеткіштерінің жүйесі ұсынылған. Мақаланың мақсаты – көмір өндіруші кәсіпорынның энергия тиімділігін бағалау детерминанттарына талдау жүргізу. Жалпы өнеркәсіптік кәсіпорындардың энергия тиімділігін бағалаудың қолданыстағы әдістері мен тәсілдері қарастырылады. Көмір өндіру кәсіпорындарының энергия тиімділігі көрсеткіштерінің жүйесін ресімдеуге авторлық көзқарас ұсынылады.

Энергия тиімділігін бағалау үшін энергетикалық аудиттің маңыздылығы көрсетіліп, оның кезеңдері көрсетілген. Көмір өндіруші кәсіпорынның энергия тиімділігіне әсер ететін факторлар да жүйеленіп, энергия тиімділігін арттыру шараларын іс жүзінде жүзеге асыруға кедергі келтіретін кедергілер талданады. Шахталардың энергия тиімділігін арттыруға көмектесетін шаралар белгіленді.

Түйін сөздер: энергия тиімділігі, бағалау, шахта, ресурстар, шығындар, тау-кен өнеркәсібі, көрсеткіштер жүйесін ресімдеу, кедергілер

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ДЕТЕРМИНАНТЫ ОЦЕНКИ ЭНЕРГОЭФФЕКТИВНОСТИ УГЛЕДОБЫВАЮЩЕГО ПРЕДПРИЯТИЯ

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Аннотация. Статья посвящена рассмотрению вопросов, связанных с оценкой энергоэффективности угледобывающего предприятия. Для угледобывающих предприятий характерным является большой объем энергоемких операций по добыче руды. В статье представлены возможные пути энергосбережения в горнодобывающей промышленности. В процессе исследования представлена система показателей энергоэффективности предприятий угледобычи. Цель статьи заключается в проведении анализа детерминант оценки энергоэффективности угледобывающего предприятия. Рассмотрены существующие методы и подходы для оценки энергоэффективности

промышленных предприятий в целом. Предложен авторский подход к формализации системы показателей энергоэффективности предприятий угледобычи. Обозначена значимость энергоаудита для оценки энергоэффективности и выделены его этапы. Также систематизированы факторы влияния на энергоэффективность угледобывающего предприятия, проанализированы барьеры, препятствующие практическому внедрению мер по энергоэффективности. Обозначены мероприятия, которые будут способствовать повышению энергоэффективности шахт.

Ключевые слова: энергоэффективность, оценка, шахта, ресурсы, затраты, горгодобывающая промышленность, формализация системы показателей, барьеры

Introduction

Nowadays, energy efficiency in the industrial sector has gained importance due to the trend of increasing energy costs as well as environmental concerns. Coal mining operations are characterised by a large volume of energy intensive ore extraction operations. Overall, energy consumption in the mining industry is estimated at 6.2 per cent of total global consumption. For example, in the USA, energy used in this industry accounts for 3.3 % of total industrial expenditure, while the South African mining sector consumes 6 % of all energy produced in the country (Palyanitsina et al., 2021; Korshak et al., 2019; Korshak et al., 2020). It is undeniable that energy efficiency in the mining industry is important to minimise energy costs and ore production costs. In addition, rational use of energy can lead to significant reductions in greenhouse gas emissions. This is a realistic goal for the mining industry. Today, all major mining companies that are members of the International Council on Mining and Metals have committed to achieving zero carbon emissions by 2050 or earlier. Most of them have also set targets for progress, such as 30 per cent by 2030 (Pshenin et al., 2023; Kusimova et al., 2023; Korshak et al., 2023).

Inefficient energy consumption in the coal mining industry is associated with significant additional costs. This can often be a sign of poor engineering or investment decisions, which in turn affect plant productivity, maintenance, safety and environmental performance. This situation requires a structural approach to modernisation and energy management, and the use of effective energy management practices, the basis of which is a comprehensive assessment of the level of energy efficiency of production (Malozyomov et al., 2023).

For example, data from coal mines in Australia show that the largest amount of energy savings, or 4.61 PJ, came from projects focused on energy management parameters, accounting for 55 per cent of all savings opportunities identified at mines (Figure 1).

Fig. 1 – Energy saving opportunities in the mining industry (PJ/year) (Molaei et al., 2021)

At the same time, it should be noted that currently there is no unified theoretical and methodological basis for determining and analysing the energy efficiency indicators of coal mining enterprises. The existing developments concern only certain aspects of this issue, for example, exclusively macroeconomic measurement at the industry level or only individual technological processes.

Thus, these circumstances confirm the relevance of the topic of this article and testify to its scientific and practical significance.

The complexity of the problem of energy efficiency improvement determines a wide range of research in this direction. The influence of economic, organisational and technical factors on the energy efficiency of an industrial enterprise was considered in their works by O.V. Kondrakov, V.Y. Mishakov, I.G. Lukmanova, R.S. Golov, V.V. Mylnik, V.G. Smirnov, Stefan Krämer, Sebastian Engell, Hongming Na, Tao Du, Wenqiang Sun, Jianfei He. (Filina et al., 2024; Gridina et al., 2023).

Methods for determining the economic efficiency of energy saving measures in the mining industry are considered in the works of Koksharov V.A., Kirshina I.A., Nepshi F.S., Krasilnikov M.I., Perevalov K.V., M. Jibran S. Zuberi, Martin K. Patel, Robert Williams.

A.E. Valiullin, I.D. Naletov, N.T. Amosov, M.V. Zhuravleva, F.R. Garieva, Stefan Scharl, Aaron Praktiknjo devoted their publications to the development of tools to stimulate the energy efficiency of the enterprise and justification of the directions of energy saving potential management.

Methods

While appreciating the achievements of scientists in the field of industrial development and energy saving policy, it should be noted that a number of issues require more extensive research. For example, energy consumption indicators that take into account the technological features of mines deserve special attention. In addition, most publications describe traditional methods of thermodynamic analysis in terms of energy equilibrium and study of energy efficiency of individual mining stages. However, there is still no clear analysis of the energy distribution between the different vital stages of coal design, development, mining and transport. As a result, the lack of analyses of coal mine design, coal washing and coal mining has led to gaps in energy efficiency studies of the entire coal industry.

Thus, the purpose of the article is to analyse the determinants of energy efficiency assessment of a coal mining enterprise.

First of all, we note that the assessment of energy efficiency of a coal mining enterprise is a systematic approach to the analysis of all data, technologies and systems related to energy consumption in order to quantify the current level of energy consumption and the savings that can be achieved by optimising the energy consumption of industrial processes.

To date, several methods and approaches have been developed to assess the energy efficiency of industrial enterprises in general. The most common of them are the following.

1. Graphs of energy consumption versus production or other parameters. This method makes it possible to identify the relationship between energy consumption and production. It also makes it possible to establish thresholds at which energy consumption changes dramatically.

2 Benchmarking. The use of energy efficiency indicators helps to determine whether a process, facility or department is functioning optimally. Benchmarking can be used to compare actual energy consumption with theoretical (calculated or modelled) energy consumption. It can also be used to compare plants, sites, processes, shifts, operators and other

aspects.

3. Pinch Analysis. An evaluation method based on graphical analysis that allows the design of complex thermal systems to be optimised to maximise heat recovery. For processes or installations with complex hot and cold flows, pinch analysis can identify opportunities for better heating and cooling. The use of this method requires engineering expertise.

However, there is no doubt that regardless of the method or approach used to assess energy efficiency and identify energy saving reserves at coal mining enterprises, it is important to use an adequate system of indicators. A number of publications suggest using an integral indicator for any industrial production:

$$E = \sum_{j=1}^{m} \frac{D_j}{\sum_{i=1}^{n} T_{ij}} \cdot K_{Ej}, \quad (1)$$

where – total value added arising from the production of products (provision of services) in the j-th technological process, rub; – total volume of consumed fuel and energy resources (FER) of the i-th type in the j-th technological process, (natural expression); – dimensionless energy intensity coefficient of the j-th technological process; j – technological process at the enterprise; m – number of technological processes at the enterprise; i – type of energy resource; n – number of FER types.

Results

In the author's opinion, this indicator will not always be sufficiently informative for coal mining enterprises, because its generalised and universal nature is not able to reflect different levels of production and the specifics of the mining industry. In this regard, we believe that to assess the energy efficiency of mines, energy consumption indicators should be developed at different levels of aggregation, depending on the purpose of use and the amount of available information. The level of aggregation is important because it determines the extent to which structural differences influence the observed results.

Fig. 2 shows the author's approach to the formalisation of the system of energy efficiency indicators of coal mining enterprises.

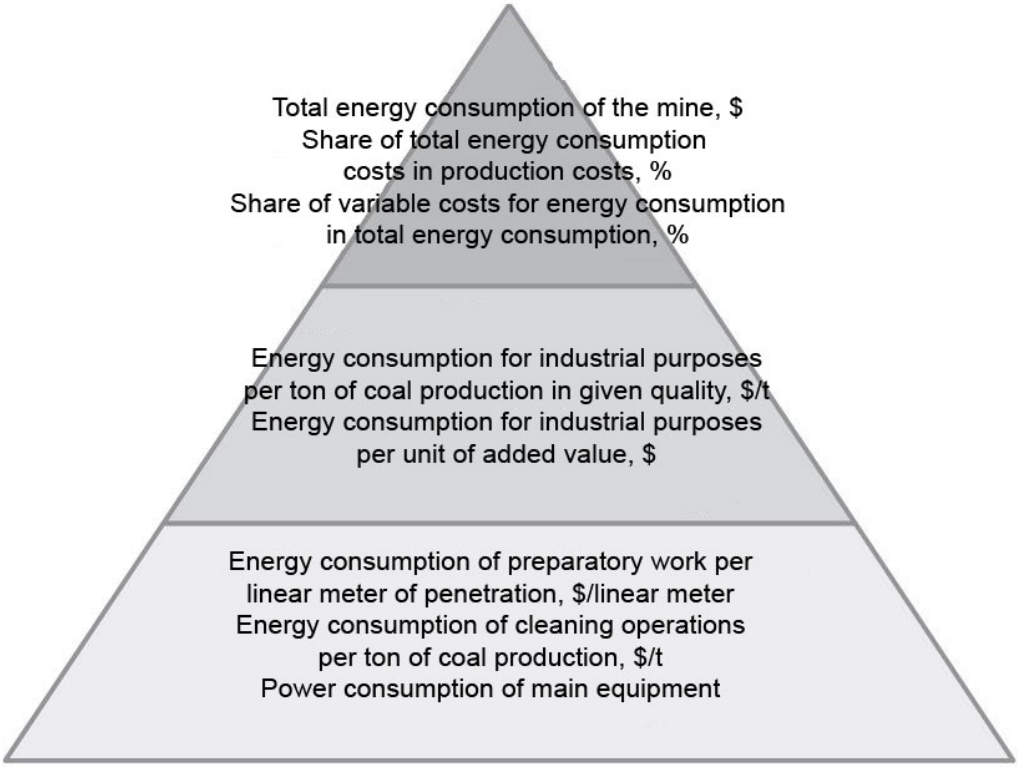

Fig. 2 – System of energy efficiency indicators for coal mining enterprises

At the first level of the pyramid are indicators that assess the energy efficiency of specific production sites, technological processes or equipment.

As an example of evaluation at this level, Table 1 presents the results of all collected data and analysed energy inputs for different processes in open pit mines in Indonesia.

Table 1 – Energy costs of surface mining processes in Indonesia (Rosado-Tamariz et al., 2020)

Mining process	Low energy costs*	High energy costs*	Average energy consumption*	%
Drilling	0.13	29	14.56	3.38
Blasting	56	275	165.50	39.85
Loading of materials	15	98	56.50	13.53
Transport	65	158	111.50	26.81
Mine dewatering	0	86	43.00	10.39
Auxiliary equipment for the mine	6	44	25.00	6.04

* ($/kilotonnes of material recovered)

The second level of the pyramid calculates the energy efficiency of the mine as a whole, which is defined as the ratio of energy consumption to value added. The value added

should be used in constant prices to avoid errors caused by fluctuations in the money market. In addition, since the total energy consumption of the mine is not directly correlated with value added, energy consumption for production needs should be included in the calculation. This indicator will provide an initial estimate of the overall energy intensity of an individual site and its trends. Due to the heterogeneity of the qualitative characteristics of coal produced at different enterprises, and, consequently, the impact of the tonne of production on cash flow, we propose to calculate the energy intensity of a unit of production in physical terms as the ratio of energy consumption for industrial needs to the volume of production (Gendler et al., 2018; Gridina et al., 2022).

At the third, most aggregated level, the total energy consumption of the coal mining enterprise in monetary terms is calculated, as well as the share of energy consumption costs in the cost price and the share of energy consumption for production purposes in the total energy consumption structure of the mine. These indicators provide a generalised picture of the energy efficiency of the enterprise and enable a comparative assessment of different mines.

An integral element of assessing the energy efficiency of a coal mining enterprise is an energy audit, which allows to identify energy saving opportunities, optimise the structure of energy use and improve operations.

Energy audit at a coal mining enterprise includes the following stages:

1. Collect and analyse historical energy consumption data for energy balance.

2- Study of the mine site and its operations. This includes identifying the most energy intensive processes and equipment.

3. Drawing up an energy balance, which assesses the main energy users and then compares them with the level of energy consumption. The energy balance includes all energy sources such as electricity, diesel, natural gas and renewable energy.

4. Identify and justify potential energy conservation measures that can reduce energy consumption and/or costs.

5. Conduct engineering and economic analyses of potential energy saving measures.

6. Calculation of carbon dioxide emissions to determine the baseline carbon footprint and future impact of energy conservation measures.

7. Preparation of a prioritised list of energy saving measures.

A special emphasis should be made on the fact that in the process of energy audit the factors affecting the energy efficiency of a coal enterprise are identified. Analysing these factors and singling out the most significant of them is necessary to create a methodology for assessing their impact and developing measures to improve energy efficiency of production as a whole. In most cases, the influence factors are divided into organisational, economic, technological (Khazin, 2023). At the same time, taking into account the possibilities of modern digital technologies and the achievements of the Fourth Industrial Revolution, we propose to systematise the factors by dividing them into 2 groups: innovative and traditional. A detailed description of these factors is given in Table 2.

Table 2 – Factors influencing the energy efficiency of a coal enterprise

Innovation factors	Traditional factors
Introduction of innovative energy efficiency programmes at the enterprise	Financial stability of the company

Participation of the enterprise in state and non-state energy saving programmes	Incentivising personnel to save energy resources
Financing the development and use of new energy-saving and smart technologies	Reducing the share of energy costs in the cost of production
Use of energy-saving equipment	Raising the qualifications of personnel in the field of energy saving
Utilisation of secondary fuel and energy resources	Continuous and accurate control of energy resources utilisation at the enterprise
Generation of energy resources by own energy sources	

At the same time, along with all the advantages and benefits of energy auditing, its limitations should be taken into account. For example, most energy audit approaches do not take into account design, planning and procurement decisions (Karlina et al., 2023; Kondratiev et al., 2022). Such factors can complicate the process, preventing accurate data from being obtained. In addition, audits typically fail to consider energy impacts due to the dynamic nature of the mine site. For example, auditors typically cannot account for changes in ore quality, changes in production schedules, or employee turnover. These changes may mean new opportunities for energy efficiency improvements. Or they may result in the levelling off of previous gains. Therefore, energy audits should be conducted regularly or when major operational processes change (Kondratiev et al., 2016; Kondratiev et al., 2022; Evdokimov et al., 2024).

Despite the importance and obvious relevance of energy efficiency tasks, there are barriers in this area that hinder its development, namely:

- economic and energy efficiency policies at the state and sectoral levels are non-systematic;
- economic levers are non-transparent and often constrain development (cross-subsidisation, tariff setting, monopolism);
- the current tariff policy does not incentivise the best and most efficient enterprises;
- deficit of financial resources for modernisation and energy efficiency projects (Kanoglu et al., 2007; IEA, 2019).

Obviously, overcoming these barriers requires proactive government policy and the efforts of mining enterprises themselves. At the level of business entities, we believe that the following measures will contribute to improving the energy efficiency of mines (Peralta et al., 2019; Udemba et al., 2022):

1. Utilising intelligent technology for blasting operations.
2. Modernisation of coal transportation equipment.
3. Improving the energy efficiency of ore processing.
4. Introduction of advanced engineering solutions that allow, for example, to improve maintenance of ventilation systems, reduce the frequency of using water sprayers, etc. (Malozyomov et al., 2024)

Conclusion

Summarising the above, we note that the assessment of energy efficiency of a coal mining enterprise allows us to understand how and where energy is used, where its use can be improved, and how to reduce costs. To carry out the assessment, the article proposes a system of indicators, highlights the features of energy audit. It also systematises the factors influencing the energy efficiency of a coal mining enterprise, analyses the barriers to the practical implementation of energy efficiency measures and outlines the measures that will contribute to improving the energy efficiency of mines.

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