sustainability

Article

Assessment of Energy Efficiency Projects at Russian Mining Enterprises within the Framework of Sustainable Development

Marina A. Nevskaya, Semen M. Raikhlin * and Amina F. Chanysheva

Department of Organization and Management, Empress Catherine II Saint Petersburg Mining University, 21 Line, 2, 199106 St. Petersburg, Russia; nevskaya_ma@pers.spmi.ru (M.A.N.)
* Correspondence: semen8991@mail.ru; Tel.: +7-(999)-206-19-21

Abstract: The mining industry is a basic sector of the Russian economy. Sustainable Development Goals appear in the strategies of mining companies and are ensured, inter alia, by increasing the energy efficiency of enterprises and plants within their structure through the implementation of projects. The lack of generally accepted criteria for assessing energy efficiency determines the need to develop a methodology that would allow taking into account the contribution of the results of projects of different scales and levels of implementation to improve the energy efficiency of the mining enterprise and the company as a whole. The purpose of the study is to develop a methodology for the comprehensive assessment of projects aimed at improving the energy efficiency of mining enterprises in the context of sustainable development. The research method is based on establishing a logical relationship between the goals of sustainable development, the principles of the "energy trilemma", criteria and results of the implementation of projects aimed at improving the energy efficiency of the mining enterprise, taking into account the systematization of these projects. The authors develop a methodology for assessing projects related to the energy efficiency of mining enterprises. The methodology is based on a two-level system of criteria: the first-level criteria characterize the degree of realization of project objectives in accordance with the goals of sustainable development and the principles of the "energy trilemma". The first-level criteria consist of the following: economic efficiency, ecological performance, reliability and safety, and flexibility. The second-level criteria characterize the economic results of the project based on the assessment of its economic efficiency. In order to provide a comprehensive economic assessment of various project outcomes, a set of indicators is proposed. The assessment of this methodology has been tested using the example of projects implemented at the mining enterprise "Albazinsky GOK" (mining and processing complex). Implementation of a comprehensive project, including the transition to a centralized power supply source, installation of a wind generator, photovoltaic installation, and energy storage system, will allow the enterprise to reduce CO_2 emissions by 100% and increase the flexibility of the enterprise's power system by 33%. The economic effect will amount to RUB 1252.5 mln (due to savings on electricity costs). The obtained results can be used by managers of mining companies to select and assess projects aimed at improving energy efficiency.

Keywords: sustainable development; energy trilemma; evaluation criteria; energy efficiency improvement projects; economic evaluation

check for updates

Citation: Nevskaya, M.A.; Raikhlin, S.M.; Chanysheva, A.F. Assessment of Energy Efficiency Projects at Russian Mining Enterprises within the Framework of Sustainable Development. *Sustainability* **2024**, *16*, 7478. https://doi.org/10.3390/su16177478

Academic Editor: Enrique Rosales-Asensio

Received: 11 June 2024
Revised: 21 August 2024
Accepted: 23 August 2024
Published: 29 August 2024

1. Introduction

Increasing the energy efficiency of various sectors and the economy as a whole is considered a global problem caused by the long-term consumption of non-renewable natural resources and their emerging shortage for a number of countries, as well as greenhouse gas emissions due to the use of carbon-based energy sources. The 2015 Paris Agreement on Climate Change [1] and the adoption of the Sustainable Development Goals (SDGs) served as a turning point in the global community's commitment to a sustainable future for society. In the same year, to solve the problem of finding a balance between reliability, accessibility, and sustainability of energy production and consumption when implementing sustainable energy projects, the World Energy Council proposed the concept of the "energy trilemma" [2,3] as well as an indicator—the "energy trilemma index" [4]—used to assess the energy sustainability of different countries and rank them.

The energy sustainability of countries is influenced by various factors [5,6], along with the state of energy consumption in non-energy industries. In particular, the raw materials industry as a whole does not belong to high energy-intensive industries. The share of electricity costs in the cost price for single companies can reach up to 40% [7], and for some large companies, there is an increase in the energy intensity of production and products [8,9].

This situation is explained by the specifics of mining production: the production structure of mining complexes, deposit development technologies, the use of a large amount of energy-intensive equipment, increased requirements for the safety of production processes (ventilation, drainage, lighting, etc.), which leads to an increase in energy costs as the depth of development increases.

In Russia, more than 70% of mineral extraction is carried out by open-pit mining [10]. The further development of open-pit mining is associated with an increase in the depth and area of quarries, the complication of geological and technical mining conditions, and an increase in the area of alienated lands [11]. At the same time, the share of energy consumption in the production process increases. All this is happening in the context of rising prices for electric energy in the world as a whole [12] and directly in Russia—from 2017 to 2022, prices increased by 28% [13].

Enrichment processes are highly energy-intensive: crushing, grinding, flotation, and magnetic separation require significant amounts of energy to process each ton of ore [14].

Thus, the problem of reducing the energy intensity of mining is urgent, especially in the context of rising energy prices [15,16]. To meet this challenge and the need to comply with the UN Sustainable Development Goals, mining companies are implementing various energy efficiency improvement projects [17,18].

The development of technologies, primarily digital, makes it possible to implement not only large but also medium and small-scale projects aimed at increasing energy efficiency at various technological stages of the production process and mining facilities. This may result in additional social, environmental, and organizational outcomes [19].

At the same time, the currently used methods for evaluating projects, especially small-scale ones, do not always allow for assessing their economic effectiveness due to the difficulties in the monetization of the resulting non-economic effects, while the current national standards in the field of energy efficiency in the Russian Federation do not recommend any quantitative criteria to assess the results achieved [20,21]. The literature review showed the existing gap in the studies devoted to assessing the effects of energy efficiency projects at mining enterprises. To fill this gap, the authors aim to develop a methodology for comprehensive economic evaluation of projects aimed at improving the energy efficiency of mining enterprises.

Given the above, the authors have posed the following research questions:

RQ1: Is a positive net present value (NPV) and other commercial assessment criteria sufficient conditions for assessing projects aimed at improving energy efficiency?

RQ2: Which criteria and indicators are used to assess the results and effectiveness of projects to improve the energy efficiency of mining enterprises?

To answer these RQs, the research paper is organized as follows. First of all, we analyze and systematize various projects implemented at mining enterprises to improve their energy efficiency based on the classification attributes we have identified and identify the effects of their implementation corresponding to the principles of the "energy trilemma" [2,3]; secondly, we propose a methodology for assessing the identified effects on the basis of a set of indicators developed by us, and finally, we test this methodology on the example of mining enterprise projects. We assume that the scientific novelty of the study lies in the development of a comprehensive methodological approach to evaluating energy efficiency projects at mining enterprises.

The purpose of the study is to develop a methodology for comprehensive assessment of projects aimed at improving the energy efficiency of mining enterprises in the context of sustainable development.

Sustainable development is a multidisciplinary concept aimed at ensuring the harmonious interaction of economic, social, and ecological systems in order to meet the needs of modern society without compromising the ability of future generations to meet their needs. The concept is based on the principle of balance between resource and energy efficiency, fairness in the distribution of benefits, and the conservation of biodiversity and natural ecosystems [22].

The practical application of the provisions of the concept of sustainable development is reflected in the Sustainable Development Goals (SDGs) defined by the document "Agenda 2030", approved by the UN in 2015. The document contains 17 SDGs aimed at solving the main challenges related to social, economic, and environmental issues.

International agreements related to climate change are aimed at developing the clean energy sector and reducing CO_2 emissions. This is being done in the context of increasing energy demand driven by demographic growth, urbanization, and industrialization [23,24]. In particular, the United Nations Sustainable Development Goal 7 (SDG 7) calls for the execution of three key tasks by 2030: ensuring universal access to available, reliable, and modern energy services, increasing the share of renewable sources in the overall energy consumption, and doubling global energy efficiency indicators [25].

In the context of multiple interrelated goals, there is a need to assess the progress not only at the state level.

The study [26] notes that the Russian business community has a tendency to plan its strategic development for 5 years, incorporating the principles and goals of sustainable development into it. In recent years, Russian companies have demonstrated their commitment to socially responsible practices and Sustainable Development Goals, which is confirmed by official reports. Such an analysis, in turn, forms the basis for decision-making by relevant stakeholders [27–29].

The paper [30] presents a conceptual model of sustainable energy development at three levels: the state, energy industries, and energy enterprises. However, this model does not consider the enterprises of other industries, which may be large consumers of energy resources and can potentially improve energy efficiency.

In foreign practice, the Global Reporting Initiative Environmental standards are used for reporting on the impact of a company's activities on the economy, environment, and society.

Many large Russian mining companies also report on sustainable development and the achievement of SDGs. ESG (environmental, social, governance) is a very common approach among Russian mining companies—an approach in which environmental, social, and corporate governance aspects are considered in the process of making investment and management decisions [31].

The "energy trilemma" developed within the framework of the sustainable development concept is considered a tool for assessing national energy systems [32]. The energy trilemma is defined as the need to find a balance between energy reliability, availability, and environmental impact, and it focuses on three aspects. The first aspect is energy security, i.e., the country's ability to ensure reliable satisfaction of current and future energy demand. Energy equity is a country's ability to provide access to affordable energy for both domestic and commercial use. Finally, environmental sustainability is an indicator of how much a country's energy systems are able to reduce their environmental impact.

The authors (Shklyarskiy, Y.E.; Skamyin, A.N. et al.) [33,34] rightly point out that energy efficiency improvement should be considered as an ongoing process provided by the implementation of various projects, which are aimed at increasing the reliability and safety of energy systems in the mining companies, rational consumption, reducing losses, and improving the quality of energy resources used.

At the same time, from the authors' perspective, increasing energy efficiency should also be considered as a specific outcome of project implementation.

Energy efficiency improvement in the mining industry is provided by projects in a wide range of areas: waste heat capture, distributed generation [35], power demand management, mine drainage, ventilation, and energy generation from by-products, etc. [36].

The projects integrating renewable and non-traditional energy sources in the energy balance (introduction of hybrid energy systems) of mining enterprises remote from centralized sources have great potential [37,38].

Another relevant direction for improving energy efficiency in mining operations is the introduction of energy storage systems [39–41], which can mitigate the irregularity of renewable energy generation [42] and ensure flexibility to the energy system [41].

Projects based on digital technologies can be highly effective [33,42,43]. For example, using an artificial neural network to predict fuel flow by dump trucks in open-pit mining operations can reduce its consumption, which in turn affects the overall energy intensity of the company [44].

With a large variety of projects, the selection and evaluation of the most promising ones that meet the mining company's SDGs determines the need for their ordering and systematization. For example, the article [45] discusses the classifications of various authors (V.D. Shapiro, A.S. Tsarkov, P.S. Geizler, and O.V. Zavyalova), who developed a unified classification of investment projects according to the following criteria: area of application, method of implementation, duration, etc., with the allocation of classes, types and types of projects.

A classification of projects using a dichotomy (modified attribute) is proposed in the work [46]. The author singles out capital-intensive and ordinary projects with quick returns and with a long delay of return, federal, regional, local, and intra-company projects, interrelated and independent, alternative and non-alternative projects, etc.

The paper [47] argues that a complete classification of projects is not possible due to the numerous attributes that could be used to define classes. This results in a lack of a generally accepted framework for classifying projects due to their uniqueness and differences in terms of size, time, investment, complexity, and technological content. The author classifies projects depending on their size, complexity, and risk.

In our opinion, the systematization of enterprise projects provides a deep understanding of their diversity and specificity, which is necessary for a number of tasks:

- It allows for a reasonable approach to the selection of indicators for assessing the effectiveness of these projects based on their goals, scale, and characteristics;
- It facilitates the certification of projects, which includes the creation of standardized descriptions of each project and facilitates the process of identifying, comparing, and selecting projects for implementation, and simplifies the exchange of knowledge and experience between stakeholders;
- It helps to optimize the allocation of resources since it allows for identifying the most promising areas for investment based on the analysis of past and current projects.

However, it is important to note that in the process of systematization, it is necessary to consider a number of specific features due to the target directions and results inherent specifically to the projects aimed at improving energy efficiency.

In our opinion, evaluating projects related to energy efficiency improvement should necessarily rest on such project attributes as the main goal, type of result, relation to the production process, nature of project activities, level of results manifestation, level of project implementation, and scale.

Another important aspect of project evaluation is the choice of indicators that characterize project results. Modern studies emphasize a number of indicators that are important for assessing the efficiency and reliability of energy systems and equipment of mining enterprises [45,48,49]. The issues of the selection of basic reliability indicators for various objects are sufficiently elaborated and regulated in Russian national standards (GOST 27.003-90) [50]. One of them is the availability factor [51], which reflects the ability of the system (equipment) to perform the required functions, and the MTBF, indicating the time of failure-free operation until the first failure. The probability of uptime is also a key metric that reflects the reliability of a system over time [52].

An increase in the efficiency factor of converting the energy potential of the primary energy carrier into electrical energy [53] and the growth in the share of electrical energy storage systems (EESSs) in the total installed capacity of the power system [54] are signs of improvement in the efficiency of the enterprise energy infrastructure.

It is also important for mining enterprises to minimize the ecological impact on the environment [55], which can be achieved by optimizing the operation of the diesel generator set [56] and switching to more environmentally friendly fuels.

The structure of consumed energy resources may change depending on the share of renewable energy sources, which reflects the global trend of decarbonization and transition to more sustainable and environmentally friendly energy sources [57].

When evaluating small-scale projects at the local enterprise level, energy efficiency is considered mainly as a technological category. In this case, various evaluation indicators are used, such as the efficiency factor of the power plant, energy utilization factor [58], specific (actual) consumption of energy carrier [59], installed capacity utilization factor [59], average operating time per failure [60], etc.

It should be noted that there are no universal methodologies for assessing the social and organizational results of these projects. The scientific literature indicates that the overall economic benefits of industrial energy efficiency projects are often underestimated due to a lack of assessment of the associated various effects [61,62]. This is due to the diversity of approaches to evaluating efficiency, specifics of industries, and individual characteristics of enterprises. As a result, despite the fact that a comprehensive assessment of the impact of energy efficiency improvement projects is important, the scientific literature has not yet formed a unified methodological toolkit to assess the social and organizational effects of their implementation.

The emergence of new directions of energy efficiency improvement at mining enterprises (introduction of RES projects, energy storage, digital technologies, etc.) leads to the conclusion that it is necessary to expand the range of indicators characterizing the results and efficiency of projects.

2. Materials and Methods

The conceptual and methodological basis of the study is the concept of sustainable development and the principles of the “energy trilemma” interpreted for the mining company level.

The methodological approach involves establishing a logical relationship between the goals of sustainable development of a mining company, goals, results, and economic efficiency of projects related to improving the energy efficiency of a mining enterprise.

The general scheme of the study is presented in Figure 1 and includes several stages.

In the first stage, the target benchmarks for improving the energy efficiency of a mining company are established due to three interrelated aspects: the main SD objectives in the field of energy efficiency (“affordable and clean energy”, “rational production and consumption”, “combating climate change”), the principles of the “energy trilemma” (ET), and the way to improve energy efficiency (project implementation).

In the second stage, based on the elaboration of scientific sources, projects aimed at improving the energy efficiency of mining enterprises are analyzed to determine the directions to be implemented at the current stage of development.

In the course of the study, the need for systematization of projects due to their diversity and the definition of attributes for it was revealed. Based on the systematization of projects, a specific set of indicators and methods of their calculation is selected.

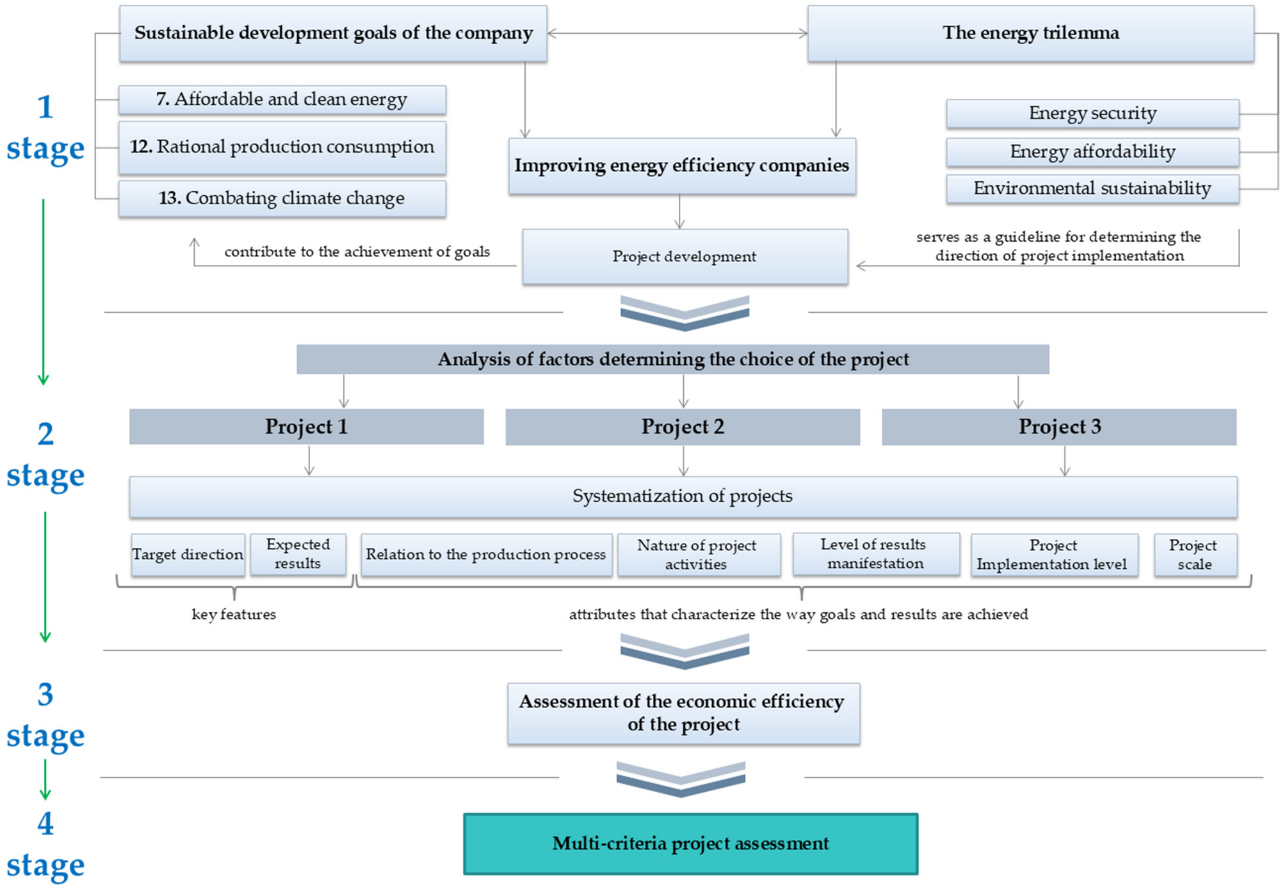

Figure 1. Logical scheme of the study. Source: compiled by the authors.

In the third stage, criterion indicators—indicators characterizing the criteria of economy, environmental friendliness, reliability and safety, and flexibility—are established. As the criterion indicators of evaluation, the absolute increase, in % of each indicator, expressed in natural units of measurement and characterizing the expected dynamics as a result of project implementation is applied.

The absolute growth of each indicator characterizing the expected dynamics as a result of project implementation was used as a criterion for assessing the results of projects. Further, the expected results were monetized, and models of their economic evaluation were built. Thus, non-economic results were valued.

In the fourth stage, a multi-criteria evaluation of the project is performed, which allows taking into account the maximum "contribution" of the energy efficiency project to the achievement of the set goals and the economic evaluation of project results.

The research materials are publicly available sources of secondary information: publications of Russian and foreign authors containing information on the practice of implementing projects aimed at improving energy efficiency in the mining and mineral processing sector.

3. Results

3.1. Energy Trilemma Principles Interpreted for the Mining Enterprise Level

The specific nature of mining enterprises allows us to adapt the principles of the "energy trilemma"—the concept of sustainable development for the energy systems of countries, recommended by the World Energy Council, which consists of the following:

- The principle of "safety and reliability" considers the continuity of energy supply, the inadmissibility of disconnection from energy sources, in compliance with safety norms and standards;

- The principle of "energy equality" represents the implementation of measures to optimize energy consumption between engineering and social infrastructure facilities included in the property complex of a mining enterprise, as well as its energy sources;
- The principle of "environmental sustainability" consists of the development and implementation of technologies and processes aimed at reducing emissions of greenhouse gases, toxic substances, and other pollutants into the environment, rational use of energy in production processes, public reporting, and communication on environmental initiatives.

3.2. Systematization of Energy Efficiency Projects at Mining Enterprises

The study proposes two groups of attributes: the first group—targeting and expected results—is necessary to identify the main objectives and expected results from project implementation. These attributes allow us to clearly formulate objectives and assess the effectiveness of the project.

The attribute "target direction" (*proposed by the authors*) is conditioned by global objectives that are solved in the implementation of projects aimed at improving energy efficiency. At the same time, the achievement of the goal "reduction of energy consumption" can be achieved both through the introduction of new technologies (intensive energy saving) and through organizational changes (extensive energy saving). The objective "improving the quality of consumed and produced energy resources" envisages improving the quality of sources (primary energy resources) and more efficient energy conversion (secondary energy resources).

The attribute "result" (*proposed by the authors*) allows us to identify and summarize the possible results of projects with different objectives.

The second group of attributes serves to provide a more detailed passportization and accounting of projects.

The project attribute "relation to the production process" is conditioned by the need to define its role and place in the company's production system. This helps to determine how the project will affect the basic and auxiliary processes, plan resources, optimize operations, and ensure the best use of production capacity.

The attribute "nature of project activities" defines actions required to implement the project. This attribute helps to identify the resources, skills, and approaches that will be required for the successful implementation of the project, ensuring its targeted and effective management: organizational—changing management processes, optimizing staff work, introducing a motivation system for reducing energy consumption, training, and professional development of employees; technological—introducing new technologies or improving existing ones; technical—improving heat and power supply, introducing automation and energy consumption control systems, defect detection systems, etc.; and economic—changing the cost structure and creating a more efficient economic model for the use of energy resources.

The project attribute "level of results manifestation" classifies results based on their impact on energy efficiency: with main results—directly affect the level of energy efficiency; with additional results—do not have a direct impact on energy efficiency but create conditions for its improvement; with complex results—direct and associated results simultaneously affect the level of energy efficiency.

The attribute "project implementation level" varies from the development of individual technologies and setting up production processes to the creation or modernization of entire enterprises. This attribute helps to determine the level of implementation of the project solutions—from specific innovations to the integrated development of the company.

The attribute "project scale" is determined by the scope of work, its duration, size of investment, impact on the enterprise or society, and complexity of tasks.

The general classification is summarized in Table 1.

Table 1. Systematization of energy efficiency improvement projects. Source: compiled by the authors.

Projects' Systematization Attributes	Project Groups	Subgroups
1. Main goal	Reduction in energy consumption	• Extensive energy saving • Intensive energy saving
	Improving the quality of consumed and produced energy resources	• Improving the quality of the energy source • Increasing energy conversion efficiency
	Improving the reliability and safety of the company's power system	
	Increasing the flexibility of energy resources and energy system management	
2. Results	Technological, environmental, economic, social, organizational	
3. Relation to the production process	In basic manufacturing processes, auxiliary manufacturing processes, serving processes, and logistics and transport operations	
4. Nature of project activities	Organizational, technological, technical, economic	
5. Level of results manifestation	Main result, additional result, complex result	
6. Project implementation level	Technological process, production process, enterprise, company	
7. Project scale	Small, medium, large	

3.3. Justification of the Criteria and Indicators for Evaluation

This study proposes a two-level system of criteria and indicators for evaluation:

1. The first-level criterion is the degree of achievement of the project goals in accordance with the SDGs and ET. First-level indicators are variables characterizing this criterion;

2. Criteria and indicators characterizing the results and economic results of projects are used to assess their economic efficiency. A methodology of multi-criteria project assessment was developed, aiming at integrating four key criteria: economic efficiency, ecological performance, reliability and safety, and flexibility. Each of these criteria plays an important role in ensuring the efficient functioning of mining enterprises as a whole, as well as their energy systems.

Therefore, an energy efficiency improvement project is considered economically efficient if the following apply:

(1) The project meets one of the SDG achievement criteria (as a sufficient condition), i.e., it makes a "contribution" to accomplish specific goals. The indicators characterizing the degree of achievement of the SDGs, set by the company (the ratio of the actual achieved result to the established one), are accepted as evaluation indicators. Considering that this work introduces additional criteria of flexibility and reliability, which are not included in the company reports, the authors propose to evaluate the positive dynamics of the indicators characterizing these criteria;

(2) During the economic assessment of a project requiring investments, a positive value for the net present value (NPV) is ensured (a positive value is a necessary, but not a sufficient condition), while all additional results of the project (technological, environmental, social, organizational) should be considered as integrally as possible.

Taking into account the results of the analysis of the scientific literature, as well as the reporting on the sustainable development of large companies, the authors propose to use the following indicators as metrics. These are indicators characterizing the achievement of the SDGs as a result (Appendix A) of the project implementation according to four criteria:

(1) To evaluate the performance on the basis of an "economic efficiency" criterion:

(a) The energy intensity of the production: this indicator is determined by the ratio of the reduction in the energy intensity achieved through the implementation of the project in accordance with the SDGs;

(b) Volume of energy consumption: this indicator is determined by a decrease in consumption while maintaining the current energy efficiency indicator or improving it.

(2) To assess the project on the basis of an "ecological performance" criterion:

(a) The share of energy obtained from renewable sources: this indicator is determined as an increase in the share to that established in accordance with the SDGs;

(b) The reduction in CO_2 emissions, as well as overall harmful emissions.

(3) To study the performance on the basis of a "reliability and safety" criterion:

(a) A technical utilization coefficient: this indicator is evaluated as an increase in its value;

(b) A readiness coefficient: this indicator is determined as an increase in the equipment readiness coefficient.

(4) To evaluate the project on the basis of a "flexibility" criterion (proposed by the author):

(a) A coefficient for the use of the energy efficiency system: this indicator is defined as an overall growth;

(b) A coefficient of demand management: this is the ability of the system to manage demand and to balance generation and consumption.

The main results will be technological (technical), environmental, social, and organizational. To obtain these results, the authors use standard or well-known indicators (calculation models), quantifying them in accordance with certain parameters specific to each type of result. The expected outcomes are monetized based on the proposed models of their economic assessment, taking into account the savings of the enterprise's resources (energy, time, etc.) and a possible increase in production volumes. Thus, non-economic results receive a cost estimate.

In this study, the authors developed a set of indicators for the economic assessment of the results of energy efficiency improvement projects (presented in Appendix A).

The first column contains a list of expected (possible) results of the project, both basic and complementary. The second column contains the basic models and indicators used to assess the various non-economic results of the project. The third column characterizes the criteria for assessing the results (expected dynamics). The fourth column contains the monetized calculation of the results, which allows us to obtain a cost estimate. The authors aim to show that various projects directed at improving the energy efficiency of mining enterprises can ultimately provide energy savings and additional production volumes. At the same time, projects aimed at reducing emissions do not always provide such savings, but taking into account complementary results, including organizational ones, they can be effective. Taking into account organizational results is also necessary for assessing the organizational flexibility of the enterprise when evaluating organizational projects related to the formation of energy-saving behavior and environmental culture.

The procedure for assessing the results corresponds to one of the principles of the well-known "Methodological recommendations for assessing the effectiveness of investment projects", recommended by UNIDO—"maximum consideration of all project results," both main and additional ones [63].

3.4. Multi-Criteria Assessment Methodology

The methodology involves a sequence of four steps:

Step 1. Determining the criteria and corresponding indicators.

Selecting indicators in accordance with the company's operating conditions (Table 2).

Table 2. Criteria assessment indicators. Source: compiled by the authors.

Criterion	Indicator	Formula	Description
Economic efficiency	Energy intensity requirements	$E_{pr} = \frac{\sum W_j}{G_{pr}}$	W_j^{-}consumption of fuel and energy resources of type j, reduced to conventional units, tons of standard fuel G_{pr}—quantity of manufactured products, RUB
	Volume of energy consumption	$\sum W_j$	

Table 2. *Cont.*

Criterion	Indicator	Formula	Description
Ecological performance	Share of energy from renewable energy sources	$E = \frac{E_{RES}}{E}$	E_{RES}—energy from low-carbon sources, J E—total energy, J
	Volume of CO_2 emissions	$V_{CO_2} = V_{CO_{21}} - V_{CO_{22}}$	$V_{CO_{21}}$—volume of CO_2 emissions without the use of technology, tons $V_{CO_{22}}$—volume of CO_2 emissions using technology, tons
Reliability and safety	Technical utilization factor	$P(t) = \frac{t}{T}$	t—number of hours of equipment failure-free operation, h. T—operating time regime fund of all energy equipment and installations for the year, h.
	Equipment readiness factor	$K_g = \frac{t_w}{t_w + t_p}$	t_w—time of correct operation, h t_p—forced downtime, h
Flexibility	Utilization factor of the electricity storage network	$d = \frac{t_{ESS}}{24} \times 100\%$	t_{ESS}—number of hours of energy production from the electricity storage network, hour
	Demand management factor	$R_d = \frac{\sum P_{reduced}}{\sum P_{total}} \times 100\%$	$P_{reduced}$—power reduced on demand, W P_{total}—total power, W

Step 2. Developing a scale for level 1 indicators.

A 10-point value scale is used to assess the positive dynamics of indicators.

The developed table of point value assessment of level 1 criteria is presented below (Table 3).

Step 3. The sum of points for the project is determined, which characterizes the degree of achievement of the SDGs.

Step 4. Evaluation of the economic efficiency of the project according to the criteria of level 2. The main criterion for evaluating projects is the identification of a positive value of the net present value.

Table 3. Point value assessment indicators of level 1 criteria. Source: compiled by the authors.

Project Evaluation Criteria	Indicators	Range of Indicator Variation	Indicator Scale, Points	
1	2	3	4	
Economic efficiency	Energy intensity requirements	0–40%	0–4%—1 4–8%—2 8–12%—3 12–16%—4 16–20%—5	20–24%—6 24–28%—7 28–32%—8 32–36%—9 36–40%—10
	Volume of energy consumption	0–30%	0–3%—1 3–6%—2 6–9%—3 9–12%—4 12–15%—5	15–18%—6 18–21%—7 21–24%—8 24–27%—9 27–30%—10
Ecological performance	Share of energy from renewable energy sources	0–10%	0%—1 2%—2 3%—3 4%—4 5%—5	6%—6 7%—7 8%—8 9%—9 10%—10
	Volume of CO_2 emissions	0–100%	0–10%—1 10–20%—2 20–30%—3 30–40%—4 40–50%—5	50–60%—6 60–70%—7 70–80%—8 80–90%—9 90–100%—10

Table 3. *Cont.*

Project Evaluation Criteria	Indicators	Range of Indicator Variation	Indicator Scale, Points	
Reliability and safety	Technical utilization factor	0–100%	0–10%—1 10–20%—2 20–30%—3 30–40%—4 40–50%—5	50–60%—6 60–70%—7 70–80%—8 80–90%—9 90–100%—10
	Equipment readiness factor	0–100%	0–10%—1 10–20%—2 20–30%—3 30–40%—4 40–50%—5	50–60%—6 60–70%—7 70–80%—8 80–90%—9 90–100%—10
Flexibility	Utilization factor of the electricity storage network	0–40%	0–4%—1 4–8%—2 8–12%—3 12–16%—4 16–20%—5	20–24%—6 24–28%—7 28–32%—8 32–36%—9 36–40%—10
	Demand management factor	0–10%	0%—1 2%—2 3%—3 4%—4 5%—5	6%—6 7%—7 8%—8 9%—9 10%—10

The assessment of the economic efficiency of projects implies the application of the traditional methodology for assessing the efficiency of investment projects with the calculation of NPV (1):

$$\sum_{t}^{T} \mathrm{NPV_t} = \sum_{t=0}^{T} \frac{\mathrm{E_t} \cdot (1 - \mathrm{I_{tax}}) + \mathrm{A_t} + \mathrm{L_t}}{(1+\mathrm{i})^{\mathrm{t}}} - \sum_{t=0}^{T} \mathrm{K_t} > 0, \tag{1}$$

where $\mathrm{NPV_t}$—net discounted income at time t;

$\mathrm{E_t}$—economic effect at time t;

T—billing period;

i—discount rate;

$\mathrm{A_t}$—depreciation at time t;

$\mathrm{L_t}$—residual value at time t;

$\mathrm{I_{tax}}$—income tax rate in fractions;

$\mathrm{K_t}$—volume of investment in the project at time t.

The model for estimating the economic effect of a project is the difference between the current comprehensive economic results and the costs of achieving them (2):

$$\mathrm{E_t} = \mathrm{R_{et_t}} + \mathrm{R_{ee_t}} + \mathrm{R_{es_t}} + \mathrm{R_{eo_t}} - \sum_{m=1}^{M} \mathrm{C_{m_t}} \rightarrow max, \tag{2}$$

where $\mathrm{R_{et_t}}$—economic evaluation of the technological result;

$\mathrm{R_{ee_t}}$—economic evaluation of the ecological result;

$\mathrm{R_{es_t}}$—economic evaluation of the social result;

$\mathrm{R_{eo_t}}$—economic evaluation of the organizational result;

$\sum_{m=1}^{M} \mathrm{C_{m_t}}$—the total ongoing costs of the project associated with the various outputs;

$\mathrm{E_t}$—economic effect from the prorealization at time t.

3.5. Testing the Proposed Methodology

Using the example of the Albazinsky GOK enterprise (Polymetal AO, Albazinsky GOK, Albazino, Russia), an economic assessment of projects aimed at increasing the energy efficiency of the enterprise was conducted.

The authors propose to supplement the current project for the construction of an energy technology complex with the following project: the replacement of the energy supply for the pumping station with a rated capacity of 100 kW with renewable energy sources within the territory of the Albazinsky GOK.

However, these energy sources have the disadvantage of not being able to generate energy around the clock. Today, diesel generator equipment is used to cover the necessary demand for energy. Within the framework of this modeling, the authors propose to use an electricity storage network together with renewable energy sources.

The results of the implementation of the basic and proposed projects are presented in Appendix B (Tables A2 and A3).

As a result of the calculations, the basic project received a total of 20 points with investments of RUB 1.2 billion, and the alternative project—29 points with investments of RUB 1.279 billion.

Therefore, the second version of the project is preferable and can be recommended for implementation in order to improve energy efficiency and sustainable development of the mining enterprise.

4. Discussion

In the current geopolitical and economic conditions, energy conservation, ensuring the reliability and safety of the energy equipment, technologies, and the production energy system are priorities for mining enterprises and companies in Russia.

Mining enterprises are complex energy consumption facilities. The specifics of mining enterprises are determined by their production structure, deposit development technologies, increased requirements for the safety of production processes, their complexity and continuity, a high level of mechanization of work, the need to maintain social infrastructure, the presence of its own energy infrastructure, the possibility of diversifying energy sources, and the use of hybrid generation technologies. These features determine the conditions and create additional requirements for the energy efficiency of the enterprise and for projects to improve it. Therefore, the authors formulate some principles corresponding to the principles of the “energy trilemma”, which is recommended by the World Energy Council as a concept for the sustainable development of energy systems of countries.

Analysis of the experience of various countries in implementing energy efficiency projects has shown the possibility of their systematization according to the proposed attributes, which, on the one hand, allow taking into account the possibility of achieving the SDGs and the principles of the energy trilemma, and, on the other hand, to perform justification and comprehensive economic evaluation of projects of different levels, scales, and expected results.

For the specifics of mining enterprises, the formulated principles and proposed systematization features made it possible to define the following project evaluation criteria: cost-effectiveness, environmental friendliness, flexibility, reliability, and safety.

Economic efficiency is understood as the ability of an enterprise to use energy or other resources as efficiently as possible and with minimal losses.

Ecological performance is an assessment measure that determines the degree of negative impact of a certain technology, product, or process on the environment.

The flexibility of an enterprise’s energy system is the ability of an enterprise’s energy system to regulate the volumes and quality of consumed energy resources in accordance with changes in internal needs and the influence of the external environment.

The reliability and safety of the energy system of the enterprise is a complex property and is defined as the ability of the energy system to perform the functions of generating, transmitting, distributing, and supplying consumers with electric energy in the required quantity and standardized quality through the interaction of generating units, electrical networks, and electrical installations of consumers.

The choice of indicators to characterize each criterion was based on the following:

1. Some indicators are universal and mandatory sections in the sustainable development reports of mining companies (e.g., energy intensity or CO_2 emissions), which allows for uniformity and comparability of data between different enterprises and sectors. The choice of universal indicators for assessing the sustainable development of mining companies not only simplifies the process of collecting information but also allows stakeholders to analyze it comprehensively;
2. The analysis of the existing academic literature in the area of indicators for assessing various project outcomes has shown that certain indicators (e.g., readiness factor) are often cited as critical. Furthermore, academic papers emphasize the need to integrate these indicators into the management and reporting system to increase transparency. Thus, the choice of indicators is based not only on practical reporting requirements but also on theoretical foundations, making it more informed and in line with current trends in sustainability;
3. The criterion "flexibility" is a relatively new area of energy efficiency improvement; therefore, universal indicators for its assessment have not been developed to date. In this paper, the authors have proposed their own indicators.

When compiling the scale, the authors were guided by the following: since the change in the indicator characterizing the project's contribution to achieving the SDGs depends on the technical (technological, organizational) capabilities and conditions of the project itself, as well as the logic of the indicator–indicator construction, the "value" of one point for each indicator will be different.

For example, the transition to carbon-free energy sources will allow a 100% reduction in CO_2 emissions. At the same time, as the results of the analysis of the practice of implementation of energy-efficient projects show, the potential to reduce energy intensity at mining enterprises can reach 40%. Therefore, the "value" of 1 point in the first case is defined in the interval 0–10; in the second case, 0–4.

The following results were taken into account when calculating the NPV of the projects:

- Unit savings on energy costs of 769 RUB/ton of raw materials (formula R^9_{et}, Appendix A);
- Increase in the share of the energy storage system in the installed capacity of the power system by 33% (formula R^6_{et}, Appendix A).

The operating costs of the projects included the costs of equipment amortization and equipment maintenance. They were calculated on an aggregate basis.

Unfortunately, the authors were not able to consider the impact of the project results on the performance of the mining enterprise due to the lack of access to the financial and economic reports of the enterprise.

The choice of indicators in the study is determined by the need to measure the efficiency of production processes and equipment at the enterprise. The proposed set of indicators is the result of the generalization of methods contained in various sources and is designed to assess the results of projects, primarily at the level of technologies, processes, and structural units of the enterprise.

At the same time, in each case, the set of indicators can be customized for a specific project. When testing the methodology in our examples, we used only the indicators characterizing the results of implementation of the considered projects.

At the same time, the authors realize that the development of evaluation methods lags behind the development of technologies, so the proposed set of indicators is not closed and can be supplemented.

The choice of the object for testing the developed methodology is conditioned by several key factors. First of all, an important factor is the availability of accessible information about the project, which allows for a comprehensive analysis and ensures the reliability of the results obtained. Data availability is critical for verifying the proposed methodology and assessing its effectiveness.

In addition, the target of selection should be representative of the broader trends and characteristics of the mining industry. For example, a company with diverse projects and scale of operations provides the opportunity to evaluate the methodology in a variety of environments and scenarios, which increases its versatility.

The level of maturity and development of the facility also plays an important role. Testing the methodology on already operating projects with established processes allows for a clearer identification of both the opportunities and shortcomings of the proposed methodology. This gives a better idea of its applicability.

Finally, the selection of the site should take into account the current challenges and problems facing the mining industry. This will identify specific areas for improvement and adaptation of the methodology to current conditions.

5. Conclusions

The main results of this study are as follows:

1. The study found that energy efficiency of the basic sectors of the economy, in particular, the raw materials industry, is an essential condition for sustainable development and the achievement of its goals. In modern conditions caused primarily by the introduction of digital technologies and energy storage systems, energy efficiency can be increased through the implementation of projects. Russian and foreign practice of implementing projects aimed at improving energy efficiency, different in terms of application level, scale, and expected results, necessitates systematization of these projects for the purposes of accounting, evaluation, and reasonable choice. Currently, there is no unified classification of projects related to energy efficiency, so the paper attempts to substantiate the attributes used for systemizing projects—its goals, results, nature of project activities, scale, etc.

Such systematization and deepening of evaluation parameters will be a key element for improving the efficiency of project implementation, as well as for a reasonable analysis of their impact on economic development and environmental stability;

2. A methodological approach to assessing energy efficiency projects was proposed in this research. Based on the systematization of projects, the authors constructed a set of indicators and calculation models, which allows for taking into account various project results (technological, environmental, social, organizational) and the developed multi-criteria assessment methodology;
3. A set of indicators and calculation models has been formed, which can be applied in assessing the economic efficiency of projects (especially small ones). However, there is a need to form and integrate a more extensive and logical set of criteria that not only provide a qualitative assessment of the results achieved but also allow for a comprehensive analysis of economic benefits and effects.

Therefore, as technology develops and sources of information expand, the set of indicators can be supplemented with new ones. In our opinion, the assessment of social and organizational results and effects using a set of indicators is a promising tool;

4. The developed multi-criteria assessment methodology was tested using the example of the enterprise Albazinsky GOK, which is part of the structure of AO Polymetal. The assessment results showed that achieving the set of projects that include the enterprise's SDGs is more preferable and, if funding sources are available, can be recommended for implementation.

Prospects for further research may include improving the methodology for economic assessment of energy efficiency projects, in particular, expanding the list of indicators for assessing the technological, environmental, social, and organizational results of project implementation. Improving the reliability, safety, and flexibility of the energy systems are modern challenges for improving the energy efficiency of mining enterprises, which requires the development of universal indicators to assess these criteria;

5. In the course of the study, it was found that currently, there is a lack of regulatory framework and mandatory reporting requirements for sustainable development in the

Russian Federation in the context of implementing energy efficiency projects at mining enterprises. This situation complicates the process of data collection and analysis. At the same time, given that a significant number of enterprises already publish sustainability reports, it becomes obvious that sections on energy efficiency projects should be included in these reports. This addition will increase the transparency of the companies' activities in the field of sustainable development and also contribute to the implementation of the principles of the best available technology.

Author Contributions: Conceptualization, M.A.N. and S.M.R.; methodology, M.A.N.; software, S.M.R. and A.F.C.; validation, S.M.R., A.F.C., and M.A.N.; formal analysis, M.A.N.; investigation, S.M.R.; resources, A.F.C.; data curation, S.M.R.; writing—original draft preparation, S.M.R.; writing—review and editing, M.A.N.; visualization, A.F.C.; supervision, M.A.N.; project administration, M.A.N. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are contained within the manuscript.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. The results of energy efficiency improvement projects and their evaluation. Source: compiled by the authors.

Possible Project Outcomes	The Basic Models (Indicators) for Evaluating the Result	Criteria for Evaluating the Result	Indicators of Economic Evaluation of the Result	Note
Technological	Availability factor (system, equipment) [51] $K_g = \frac{t_W}{t_W + t_P}$	Increasing the equipment availability factor	$R^1_{et} = \Delta t_P \cdot Q_P \cdot C_P$ Increase in production volumes due to reduced downtime	t_w—operating time, h Δt_p—reduction in downtime, h Q_P—production volume, units C_P—unit production cost, RUB/unit
	Mean time between failures [64] $MTBF = \frac{\sum_1^m t_i}{m}$	Increased MTBF	$R^2_{et} = \Delta t_i \cdot Q_P \cdot C_P$ Increase in production volumes due to increase in equipment operating time	Δt_i—increasing the duration of equipment operation before failure i, h m—number of failures, units Q_P—production volume, units C_P—unit production cost, RUB/unit
	Probability of failure-free operation [53] $P(t) = \frac{N_0 - n(t)}{N_0}$	Increasing the probability of failure-free operation of equipment	$R^3_{et} = \Delta n(t) \cdot C_r$ Reduction in equipment repair costs by reducing the number of equipment failures	N_0—number of observed objects that may fail during operation, units $\Delta n(t)$—reduction in the number of objects that have failed by the moment t, units C_r—equipment repair costs as a result of failure, RUB
	Increasing the service life of a diesel generator set $\Delta T = T_2 - T_1$		$R^4_{et} = \Delta A = A_1 - A_2$ Savings due to reduced depreciation payments	T_1—standard service life without the use of technology, h T_2—the standard service life with the use of technology, h A_1—depreciation charges without the use of technology, RUB A_2—depreciation charges with the use of technology, RUB
	The efficiency of converting the energy potential of the primary energy carrier into electrical energy [53] $\eta = \frac{E}{q}$	Increasing the efficiency of the power plant	$R^5_{et} = \Delta E \cdot C_E$ Increase in electricity production	ΔE—increase in the volume of electricity production, J C_E—cos t of electricity production, RUB/J q—volume of primary energy consumption, J
	The share of electric energy storage systems (ESSs) in the installed capacity of the power system [54] $d = \frac{P_{ESS}}{P_{total}}$	Increasing the share of electricity storage	$R^6_{et} = \Delta d \cdot Q_E \cdot (P_{peak} - P_{off-peak})$ Reduction in charges for electricity consumption during peak hours	Δd—increase in the share of energy storage, W P_{ESS}—power of energy storage systems, W P_{total}—total power of the enterprise power system, W Q_E—total electricity consumption, kW P_{peak}—electricity price in the peak period, RUB/ kW·h $P_{off-peak}$—electricity price in off-peak period, RUB/kW·h

Table A1. *Cont.*

Possible Project Outcomes	The Basic Models (Indicators) for Evaluating the Result	Criteria for Evaluating the Result	Indicators of Economic Evaluation of the Result	Note
	Reduction in fuel consumption of diesel generator sets $\Delta Q = Q_1 - Q_2$		$R_{et}^{7} = \Delta Q \cdot P_T$ Reduction in fuel costs	Q_1—volume of fuel consumption without the use of technology, l. Q_2—volume of fuel consumption with the use of technology, l. P_T—fuel price, RUB/l
	Reduction in electricity losses $\Delta E = E_1 - E_2$		$R_{et}^{8} = \Delta E \cdot P_{kWh}$ Reduction in energy costs	E_1—volume of electricity consumption without the use of technology, kWh E_2—volume of electricity consumption with the use of technology, kWh P_{kWh}—price of electricity per 1 kilowatt-hour, RUB/kWh
Environmental	Reduction in harmful emissions from fuel combustion by a diesel generator set engine $\Delta V_{CO_2}\ \ V_{CO_{21}} - V_{CO_{22}}$		$R_{eec}^{9} = \Delta V_{CO_2} \cdot P_e$ Reduction in emissions charges	$V_{CO_{21}}$—volume of CO_2 emissions without the use of technology, tons $V_{CO_{22}}$—volume of CO_2 emissions with the use of echnology, tons P_e—price for emissions, RUB/ton
	Share of renewable sources in energy consumption $E = \frac{E_{RES}}{E}$	Improving the structure of consumed energy sources	$R_{eec}^{10} = \pm P_{RES} \cdot \Delta Q_{res}$ Savings (costs) when using renewable energy sources	V_{RES}—energy from low-carbon sources, J V—total energy, J P_{RES}—price of renewable energy sources, RUB/J ΔQ_{res}—change in the volume of renewable resources, J
Social	Increasing the level of qualifications of employees	$R_{es}^{11} = \left(Z - \frac{Z \cdot i_z}{i_L}\right) \cdot Q_p$ Reduction in wage costs		Z—expenses on the item "wages" in the current year per RUB 1 of commercial products, RUB i_z—wage index i_L—labor productivity index Q_p—output in the planned year in wholesale prices of the enterprise, units
Organizational	Reducing the loss of an employee's working time	$R_{eo}^{12} = \Delta t \cdot Q_P \cdot C_P$		Δt—amount of working time spent on production, man-hours. Q_P—volume of production output, units/man-hours C_P—unit cost of production, RUB/unit
	Reduction in inefficient jobs	$R_{eo}^{13} = \Delta n \cdot Z_w$		Δn—number of ineffective jobs cut Z_w—average salary per laid-off employee, RUB
	Energy-saving behavior and active participation in projects to reduce energy consumption	$R_{eo}^{14} = \Delta N \cdot \Delta B \cdot P_{en}$ Reducing staff training costs		N—number of people involved in organizational measures, units B—volume of energy resources per 1 employee, unit/person P_{en}—price of energy resources, RUB/unit

Appendix B. Comparison of Energy Efficiency Improvement Projects at the Albazinsky GOK

Table A2. Results of economic evaluation of the baseline energy efficiency improvement project. Source: compiled by the authors.

Criterion	Indicator	Indicator Change	Indicator Scores	Criterion Scores	Volume of Investments, RUB bln.	Cumulative NPV, RUB bln.
Project for the construction of an electric power complex						
Economic efficiency	Energy intensity requirements	Unchanged	0	10	1.2	3.5
	Volume of energy consumption	Is down 66%	10			
Ecological performance	Share of energy from renewable energy sources	Unchanged	0	10		
	Volume of CO_2 emissions	Emissions in scope 1 are reduced by 100%	10			

Table A2. *Cont.*

Criterion	Indicator	Indicator Change	Indicator Scores	Criterion Scores	Volume of Investments, RUB bln.	Cumulative NPV, RUB bln.
Reliability and safety	Technical utilization factor	Unchanged	0	0		
	Equipment readiness factor	Unchanged	0			
Flexibility	Utilization factor of the electricity storage network	Unchanged	0	0		
	Demand management factor	Unchanged	0			
Total				20	1.2	3.5

Table A3. Results of economic evaluation of the supplemented energy efficiency improvement project. Source: compiled by the authors.

Criterion	Indicator	Indicator Change	Indicator Scores	Criterion Scores	Volume of Investments, RUB bln.	Cumulative NPV, RUB bln.
Project for construction of a power complex, application of renewable energy sources, and energy storage system						
Economic efficiency	Energy intensity requirements	Unchanged	0	10	1.2 (*base project*) 0.079 (*additional project*)	3.5 (*base project*) 0.094 (*additional project*)
	Volume of energy consumption	Is down 66%	10			
Ecological performance	Share of energy from renewable energy sources	Is up 0.02%	1	11		
	Volume of CO_2 emissions	Emissions in scope 1 are reduced by 100%	10			
Reliability and safety	Technical utilization factor	Unchanged	0	0		
	Equipment readiness factor	Unchanged	0			
Flexibility	Utilization factor of the electricity storage network	Is up 33%	8	8		
	Demand management factor	Unchanged	0			
Total				29	1.2	3.5

References

1. Dimitrov, R.S. The Paris Agreement on Climate Change: Behind Closed Doors. *Glob. Environ. Polit.* **2016**, *16*, 1–11. [CrossRef]
2. World Energy Trilemma. Time to Get Real—The Case for Sustainable Energy Investment. *World Energy Counc.* **2013**, *52*, 113. Available online: https://www.worldenergy.org/assets/images/imported/2013/09/2013-Time-to-get-real-the-case-for-sustainable-energy-investment.pdf (accessed on 8 March 2024).
3. Marti, L.; Puertas, R. Sustainable Energy Development Analysis: Energy Trilemma. *Sustain. Technol. Entrep.* **2022**, *1*, 100007. [CrossRef]
4. Song, M.; Latif, M.I.; Zhang, J.; Omran, M. Examining the Energy Trilemma Index and the Prospects for Clean Energy Development. *Gondwana Res.* **2023**, *122*, 11–22. [CrossRef]
5. Nevskaya, M.A.; Raikhlin, S.M.; Vinogradova, V.V.; Belyaev, V.V.; Khaikin, M.M. A Study of Factors Affecting National Energy Efficiency. *Energies* **2023**, *16*, 5170. [CrossRef]
6. Pavel, T.; Amina, A.; Oleg, K. The Impact of Economic Development of Primary and Secondary Industries on National CO_2 Emissions: The Case of Russian Regions. *J. Environ. Manag.* **2024**, *351*, 119881. [CrossRef]
7. Makarova, L.M.; Rodina, E.E. Management Accounting of Energy Costs. *Forum Fam. Plan. West. Hemisph.* **2019**, 162–168. (In Russian)
8. Official Website of RUSAL. Sustainability Report for 2022. Available online: https://rusal.ru/sustainability/report/ (accessed on 8 March 2024). (In Russian)

9. Official Website of PJSC Severstal. Sustainability Report for 2022. Available online: https://severstal.com/rus/ir/indicators-reporting/social-reports (accessed on 8 March 2024). (In Russian)
10. Official Website of HammerMaster. Mining in Quarries and Open Pits. Available online: https://hammermaster.ru/stati/dobycha-poleznykh-iskopaemykh-v-karerakh-i-razrezakh (accessed on 8 March 2024).
11. Larichkin, F.D.; Knysh, V.A.; Nevskaya, M.A.; Fedoseev, S.V.; Bloshenko, T.A.; Melik-Gaikazov, I.V.; Perein, V.N.; Novoseltseva, V.D.; Goncharova, L.I.; Gilyarova, A.A. *Rational Use of Secondary Mineral Resources in the Conditions of Ecologization and Implementation of the Best Available Technologies*; Publishing house of FIS KSC RAS: Apatites, Russia, 2019; ISBN 9785911374174. (In Russian)
12. Bolton, P. Gas and Electricity Prices During the 'Energy Crisis' and Beyond/Paul Bolton. Available online: https://commonslibrary.parliament.uk/research-briefings/cbp-9714 (accessed on 8 March 2024).
13. Russian Electric Power Industry: 20 Years of Reforms. Analytical Center for Fuel and Energy Complex. Available online: https://www.bigpowernews.ru/photos/0/0_sPRMFOSQOiredLNqtTHGsuoEUICUROHk.pdf (accessed on 8 March 2024). (In Russian)
14. Nikolaeva, N.V.; Kallaev, I.T. Features of Copper–Molybdenum Ore Grinding. *MIAB. Min. Inf. Anal. Bull.* **2024**, 52–66. [CrossRef]
15. Liu, X.; Meng, X. Evaluation and Empirical Research on the Energy Efficiency of 20 Mining Cities in Eastern and Central China. *Int. J. Min. Sci. Technol.* **2018**, *28*, 525–531. [CrossRef]
16. Jamali, S.; Wittig, V.; Börner, J.; Bracke, R.; Ostendorf, A. Application of High Powered Laser Technology to Alter Hard Rock Properties towards Lower Strength Materials for More Efficient Drilling, Mining, and Geothermal Energy Production. *Geomech. Energy Environ.* **2019**, *20*, 100112. [CrossRef]
17. Cherepovitsyn, A.; Tsvetkova, A.; Komendantova, N. Approaches to Assessing the Strategic Sustainability of High-Risk Offshore Oil and Gas Projects. *J. Mar. Sci. Eng.* **2020**, *8*, 995. [CrossRef]
18. Dmitrieva, D.; Solovyova, V. Russian Arctic Mineral Resources Sustainable Development in the Context of Energy Transition, ESG Agenda and Geopolitical Tensions. *Energies* **2023**, *16*, 5145. [CrossRef]
19. Lebedev, A.; Cherepovitsyn, A. Waste Management during the Production Drilling Stage in the Oil and Gas Sector: A Feasibility Study. *Resources* **2024**, *13*, 26. [CrossRef]
20. *GOST R 56828.24-2017*; Best Available Techniques. Energy Saving. Guidance on the Application of the Best Available Techniques for Increasing the Energy Efficiency Energy Saving. Available online: https://docs.cntd.ru/document/1200146366 (accessed on 8 March 2024). (In Russian)
21. *GOST 31532-2012*; Energy Conservation. Energy Efficiency. Composition of Indicators. Basic Concepts. Available online: https://docs.cntd.ru/document/1200102302 (accessed on 8 March 2024). (In Russian)
22. Hajian, M.; Jangchi Kashani, S. Evolution of the Concept of Sustainability. From Brundtland Report to Sustainable Development Goals. In *Sustainable Resource Management*; Elsevier: Amsterdam, The Netherlands, 2021; pp. 1–24.
23. Lee, K.-Y.; Tsao, S.-H.; Tzeng, C.-W.; Lin, H.-J. Influence of the Vertical Wind and Wind Direction on the Power Output of a Small Vertical-Axis Wind Turbine Installed on the Rooftop of a Building. *Appl. Energy* **2018**, *209*, 383–391. [CrossRef]
24. Marinina, O.; Nevskaya, M.; Zhang, L.; Que, C.T. Analysis of the Influence of Macroeconomic Factors on the Sustainable Development of the Chinese Coal Industry. In Proceedings of the 21st International Multidisciplinary Scientific GeoConference SGEM 2021, Albena, Bulgaria, 16–22 August 2021; pp. 631–638.
25. Cherepovitsyn, A.; Stroykov, G.; Nevolin, A. Efficiency of Low-Carbon Technologies Implementation at Non-Ferrous Metallurgy Enterprises under the Conditions of Carbon-Regulation Development in Russia. *Sustainability* **2023**, *15*, 16640. [CrossRef]
26. Izmailova, M.A. Sustainable Development as a New Component of Corporate Social Responsibility. *MIR (Mod. Innov. Res.)* **2021**, *12*, 100–113. [CrossRef]
27. Horan, D. National Baselines for Integrated Implementation of an Environmental Sustainable Development Goal Assessed in a New Integrated SDG Index. *Sustainability* **2020**, *12*, 6955. [CrossRef]
28. Venghaus, S.; Dieken, S. From a Few Security Indices to the FEW Security Index: Consistency in Global Food, Energy and Water Security Assessment. *Sustain. Prod. Consum.* **2019**, *20*, 342–355. [CrossRef]
29. Diaz-Sarachaga, J.M.; Jato-Espino, D.; Castro-Fresno, D. Is the Sustainable Development Goals (SDG) Index an Adequate Framework to Measure the Progress of the 2030 Agenda? *Sustain. Dev.* **2018**, *26*, 663–671. [CrossRef]
30. Shilets, E.S.; Kravchenko, V.A.; Lukyanenko, T.V. Energy Trilemma Is a Basis of the Sustainable Development of Fuel and Energy Complex. *Vestn. Inst. Econ. Res.* **2017**, 27–34.
31. Shaikh, I. Environmental, Social, and Governance (ESG) Practice and Firm Performance: An International Evidence. *J. Bus. Econ. Manag.* **2022**, *23*, 218–237. [CrossRef]
32. Resniova, E.A.; Ponomarenko, T.V.; Mosquera, A.P.U. Multi-Criteria Analysis of Directions of Strategic Development of the Energy Sector. *Eurasian Sci. J.* **2020**, *12*. Available online: https://esj.today/PDF/82ECVN220.pdf (accessed on 8 March 2024). (In Russian)
33. Shklyarskiy, Y.E.; Skamyin, A.N.; Carrizosa, M.J. Energy Efficiency in The Mineral Resources And Raw Materials Complex. *J. Min. Inst.* **2023**, *261*, 323–324.
34. Lijuan, Z.; Ponomarenko, T.V.; Sidorov, D.V. Clean Coal Technologies with Carbon Capture, Utilization and Storage in China's Coal Industry. *Min. Informational Anal. Bull.* **2024**, 105–128. (In Russian) [CrossRef]

35. Senchilo, N.; Babanova, I. Improving the Energy Efficiency of Electricity Distribution in the Mining Industry Using Distributed Generation by Forecasting Energy Consumption Using Machine Learning. In Proceedings of the 2020 International Multi-Conference on Industrial Engineering and Modern Technologies (FarEastCon), Vladivostok, Russia, 6–9 October 2020; IEEE: New York, NY, USA, 2020; pp. 1–7.
36. Levesque, M.; Millar, D.; Paraszczak, J. Energy and Mining—the Home Truths. *J. Clean. Prod.* **2014**, *84*, 233–255. [CrossRef]
37. Carvalho, M.; Romero, A.; Shields, G.; Millar, D.L. Optimal Synthesis of Energy Supply Systems for Remote Open Pit Mines. *Appl. Therm. Eng.* **2014**, *64*, 315–330. [CrossRef]
38. Awuah-Offei, K. Energy Efficiency in Mining: A Review with Emphasis on the Role of Operators in Loading and Hauling Operations. *J. Clean. Prod.* **2016**, *117*, 89–97. [CrossRef]
39. Matos, C.R.; Carneiro, J.F.; Silva, P.P. Overview of Large-Scale Underground Energy Storage Technologies for Integration of Renewable Energies and Criteria for Reservoir Identification. *J. Energy Storage* **2019**, *21*, 241–258. [CrossRef]
40. Menéndez, J.; Ordóñez, A.; Álvarez, R.; Loredo, J. Energy from Closed Mines: Underground Energy Storage and Geothermal Applications. *Renew. Sustain. Energy Rev.* **2019**, *108*, 498–512. [CrossRef]
41. Akinyele, D.O.; Rayudu, R.K. Review of Energy Storage Technologies for Sustainable Power Networks. *Sustain. Energy Technol. Assess.* **2014**, *8*, 74–91. [CrossRef]
42. Marinina, O.; Nechitailo, A.; Stroykov, G.; Tsvetkova, A.; Reshneva, E.; Turovskaya, L. Technical and Economic Assessment of Energy Efficiency of Electrification of Hydrocarbon Production Facilities in Underdeveloped Areas. *Sustainability* **2023**, *15*, 9614. [CrossRef]
43. Romasheva, N.V.; Babenko, M.A.; Nikolaichuk, L.A. Sustainable Development of the Russian Arctic Region: Environmental Problems and Ways to Solve Them. *Min. Informational Anal. Bull.* **2022**, 78–87. [CrossRef]
44. Laayati, O.; Bouzi, M.; Chebak, A. Smart Energy Management: Energy Consumption Metering, Monitoring and Prediction for Mining Industry. In Proceedings of the 2020 IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS), Kenitra, Morocco, 2–3 December 2020; IEEE: New York, NY, USA, 2020; pp. 1–5.
45. Chizhova, E.N.; Shumilova, E.Y.; Chizhov, S.F. Methodological Approaches to Project Classification. *Bull. Belgorod Univ. Consum. Coop.* **2006**, *4*, 29–38.
46. Klyuev, R.V.; Morgoeva, A.D.; Gavrina, O.A.; Bosikov, I.I.; Morgoev, I.D. Forecasting Planned Electricity Consumption for the United Power System Using Machine Learning. *J. Min. Inst.* **2023**, *261*, 392–402.
47. Soofastaei, A.; Fouladgar, M. Improve Energy Efficiency in Surface Mines Using Artificial Intelligence. In *Alternative Energies and Efficiency Evaluation*; IntechOpen: London, UK, 2022.
48. Safa, M. Classification of Construction Projects. *Int. J. Civ. Environ. Struct. Constr. Archit. Eng.* **2015**, *9*, 625–633.
49. Nazarychev, A.N.; Dyachenok, G.V.; Sychev, Y.A. A Reliability Study of the Traction Drive System in Haul Trucks Based on Failure Analysis of Theirfunctional Parts. *J. Min. Inst.* **2023**, *261*, 363–373.
50. *GOST 27.003-90*; Reliability in Engineering. Composition and General Rules for Setting Reliability Requirements. Standardinform: Moscow, Russia, 2007.
51. Stadnik, D.A.; Stadnik, N.M.; Lopushnyac, E.V.; Kumsiev, G.A. Methodological Principles of Optimal Control of Air Distribution in an Underground Mine in "Ventilation on Demand" Systems. *Izv. Tul. Gos. Univ. Nauk. O. Zemle* **2022**, 457–466.
52. Bazhin, V.Y.; Ustinova, Y.V.; Fedorov, S.N.; Shalabi, M.E.K. Improvement of Energy Efficiency of Ore-Thermal Furnaces in Smelting of Alumosilicic Raw Materials. *J. Min. Inst.* **2023**, *261*.
53. Solomentsev, O.; Zaliskyi, M.; Zuiev, O. Radioelectronic Equipment Availability Factor Models. In Proceedings of the 2013 Signal Processing Symposium (SPS), Serock, Poland, 5–7 June 2013; IEEE: New York, NY, USA, 2013; pp. 1–3.
54. Beregova, G.M.; Matveeva, K.V. Statistical Estimation of Probability of Failure-Free Operation for Quality Assurance. *Ipolytech J.* **2010**, 242–245.
55. Petrovskiy, A.N. Increased Efficiency of Eccentric Cycloidal Engagement. *Proc. High. Educ. Inst. Machine Build.* **2021**, 3–14. [CrossRef]
56. Senchilo, N.D.; Ustinov, D.A. Method for Determining the Optimal Capacity of Energy Storage Systems with a Long-Term Forecast of Power Consumption. *Energies* **2021**, *14*, 7098. [CrossRef]
57. Efimov, V.I.; Minibaev, R.R.; Korchagina, T.V.; Novikova, Y.A. On Mining Negative Environmental Impact. *Ugol'* **2017**, 66–68. [CrossRef]
58. Chervonchenko, S.S.; Frolov, V.Y. Research of the Operation of an Autonomous Electrical Complex with a Combined Composition of Backup Power Sources. *Power Eng. Res. Equip. Technol.* **2022**, *24*, 90–104. [CrossRef]
59. Neverov, E.N.; Korotkiy, I.A.; Korotkikh, P.S.; Golubeva, N.S. Perspective Directions of Decarbonization of Industrial Production with a High Carbon Footprint in Manufactured Products. *Polzunov Bull.* **2022**, 54–65. [CrossRef]
60. Kozhevnikova, L.V.; Freidkina, E.M. Energy Inspection as the Most Important Tool for Energy Saving and Improving the Energy Efficiency of an Enterprise. In Proceedings of the Economic and Management Technologies of the XXI Century: Theory and Practice, Training of Specialists, St. Petersburg, Russia, 15 November 2016; pp. 37–42.
61. *GOST 27322-87*; The Energy Balance of the Enterprise. General Concepts. Available online: https://docs.cntd.ru/document/1200011413 (accessed on 9 March 2024).
62. *GOST 27002-89*; Reliability in Engineering. Basic Concepts. Terms and Definitions. Russia Gost: Moscow, Russia, 1990.

63. Kovalenko, P.; Rokochinskiy, A.; Volk, P.; Turcheniuk, V.; Frolenkova, N.; Tykhenko, R. Evaluation of Ecological and Economic Efficiency of Investment in Water Management and Land Reclamation Projects. *J. Water Land. Dev.* **2021**. [CrossRef]
64. Worrell, E.; Laitner, J.A.; Ruth, M.; Finman, H. Productivity Benefits of Industrial Energy Efficiency Measures. *Energy* **2003**, *28*, 1081–1098. [CrossRef]