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Reserves for improving the efficiency of thermal power stations: external on-site energy examination

Abstract: This article systematizes the experience of conducting energy audits of production facilities and municipal establishments in the form of recommendations. The purpose of the analysis is to substantiate the criteria for an effective energy audit for thermal power stations. The object of the study is the formal and regulatory content of such criteria. The subject of the analysis (a prerequisite for objectification) is the systemic relationship of formal criteria with production efficiency. Based on the experience of energetic examinations, the general requirements for the subjects of the energy audit of thermal power stations are highlighted and the general approaches and the sequence of the analytical audit are recommended. It is generalized that the restoration and improvement of

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thermal power stations as elements of the Ukrainian energy system are cost-effectively provided that the relations between the customer and the energy auditor are transparent and open. From the perspective of energy management, the external on-site energy examination assesses the technical and economic performance of thermal power stations in a broad, comprehensive manner, identifying shortcomings and reserves, providing forecasting and determining the main areas of a thermal power station's operation, and improving the plant's reputation.

Keywords: energy efficiency, energy consumption, modernization, energy audit, economy

Introduction

Strengthening Ukraine's energy security in terms of approaches to the organization of energy production is a long-term investment in war conditions given the need to save energy costs while restoring numerous industrial enterprises, institutions, facilities and households. After the direct threat of Russian attacks in 2014, the main threats to Ukraine's energy security include a high level of dependence on imports of almost all types of energy resources and the unsatisfying technical condition of its heat production (Energy strategy of... 2017). The algorithm for improving the energy sector of Ukraine should be based on the principles of transition from imported raw materials to the energy-efficient development of the fuel and energy sector, with the application of modern labor organization technologies. In the energy sector of Ukraine, during the period of its independence, neither technical nor socioeconomic factors of its energy security were properly developed (Plachkov 2019). Here, energy independence is considered a socio-economic phenomenon, which is itself the status of the economy, industry, enterprise, and autonomy achieved through the priority balancing of the interests of energy producers, suppliers, and consumers regarding the structure of the energy balance, sources, and mechanisms of its formation (Honcharuk 2020a; 2020b).

In general, in macroeconomic terms, Ukraine is energy dependent due to a significant constraint on its domestic energy production, including those resulting from external factors, such as unfair aggressive competition from the Russian Federation, an element of which has become the current military conflict. In addition, the country is characterized by a long-lasting energy inefficiency inherited from Soviet times. The result of this is, in particular, a decrease in the competitiveness of the Ukrainian economy as a whole due to the increase in the production cost of goods relative to competitive industries in countries with greater energy efficiency. At the same time, based on the general theory of industrial production cost (Chuhno 2012) and its predictive models for societies with low innovative investment (in economic, labor and cultural aspects) (Inozemtsev 2000; Acemoglu and Robinson 2016), the authors assume that the systematic improvement of energy efficiency indicators of the thermal power station (TPS) through external on-site energy examination (ESEE) is perhaps the only modern alternative to the vicious circle of the constant decline in profitability of heat-energy production and the energy sector in Ukraine.

The industrial policy implemented in Ukraine was not aimed at the strategic improvement of the energy sector as the main factor in ensuring energy independence, so it was characterized by low efficiency and contributed to its deindustrialization (Markin 2022; Mykolyuk 2018).

As of 2021, Ukraine has had the potential not to restore the outdated economy (which lagged behind civilized countries by at least 2.5–3 times in terms of energy intensity), but to build a new economy that is resource- and energy-efficient and safe (Mazur 2016). As for the interests of corporations, to solve energy efficiency challenges there are alternatives to administrative influence on the monopolist ways. External energy audits and energy monitoring, provided they are professional, safe, and confidential, equally satisfy the interests of the state and its economic strata and groups. In economic terms, the production and consumption of heat and electricity are the backbones of modern industrial production, and its modernization forms the basis for reducing the production cost of goods. In addition, with the use of modern information and social technologies, monitoring and cost reduction in the process of ESEE regarding the macroeconomic perspectives is a component of the informatization of the economic entity of the TPS and the national economy as a whole; one of the stages of informatization of society as a system of the production of life in its societal means (Khmelko 1973), and post-industrial production (Toffler 1980; Stavinskii et al. 2019).

The implementation of ESEE with the use of electronic data storage and processing systems will facilitate the systematic (statistical and contextual) processing of energy loss indicators. In a broad sense, the ESEE covering not only TPSs but also other heat-energy producers and consumers can also be considered as an applied scientific and educational service. Finally, the development of an energy consumption culture through the dissemination of ESEE is likely to affect the productive and innovative aspects of the Ukrainian economy. Reducing energy costs in overall production will increase its competitiveness.

The authors define the energy efficiency of the Ukrainian energy system as the overall goal of energy audits of its particular mesosystem level elements: energy enterprises, energy-production facilities within enterprises and institutionally organized energy-consumption entities.

The purpose of the analysis is to substantiate the criteria for an effective energy audit for thermal power stations. The object of the study is the formal and regulatory content of such criteria. The subject of the analysis (a prerequisite for objectification) is the systemic relationship of formal criteria with production efficiency.

1. Materials and methods

Analytically, the authors divide the subject of research into technical and economic indicators arising from the understanding of the object of an energy audit as a system of material production (for example, the energy balance of an enterprise, its income from production, etc.), and organizational and technological indicators indicating the social and production, institutionalized

parameters of the energy audit object (for example, the factor distribution of the deficit of the energy consumption balance or the ratio between the salary of the operator of a certain boiler room and the average salary for the corresponding employment category). The authors evaluate the current energy efficiency of Ukraine in technical and economic terms using the comparison method. In the first aspect, the difference between actual operational data and design standards for typical energy equipment is indicated. In the second aspect, the energy sustainability index of Ukraine and other countries is compared. These comparisons indicate the overall potential of the development of energy production mainly in terms of parametric technical and economic indicators for energy audits.

By means of a deductive meta-analysis, the authors identify organizational and technological features of product characteristics for the countries with a high energy sustainability index taking into account the second comparison data. The grounds for their further selection are the relevance to the goals of the state policy and compliance with the principles of an information -focused market economy. Additionally, the authors emphasized the requirement for features that are currently not taken into account by government and corporate energy regulatory authorities when formulating a request for an energy audit and the requirements for it. To formulate recommendations for organizing energy audits at Ukrainian TPSs, the authors used the method of generalization of generally accepted approaches to the assessment and regulation of energy production and energy management.

The study was conducted in three stages:

- In the first stage, the condition of the existing TPSs was assessed and the trends for improving their operation were identified. The current level of the Ukrainian energy system was established with consideration to the common technical and exploitation characteristics of operating TPSs and their economic affiliation. The negative socio-economic factors of the Ukrainian energy sector problems were also considered.
- The second stage reveals the prerequisites for conducting an energy audit, namely its significance, sense, approaches, and requirements. Recommendations for the development of energy audit methods, with consideration to the interests of its subjects, were formulated. The procedure and peculiarities of the implementation of the ESEE for TPSs were described.
- At the third stage of the study, a conditional discussion, the authors analyzed and evaluated the positions of other scientists on the subject matter and determined the compliance of the recommendations with leading ideas in the scientific doctrines of modernization and sustainable development. The conclusions of the paper were formed on this basis.

2. Results

2.1. Grounds for conducting an external on-site energy examination

The majority of Ukrainian thermal power stations began their work in the nineteen-sixties and nineteen-seventies and are currently under monopoly ownership. Since the 2000s, new production facilities have not been put into operation – this is already reflected in the condition of the existing facilities. They were not qualitatively evaluated, which affected the degradation of the energy system (Teslenko et al. 2020). There is various data on the capacities of Ukrainian TPSs, in particular, almost 92% of them have exceeded the design term of operation were at an amount of 170,000 hours. About 63% were operated for more than 220,000 hours in 2014 (Skibina 2014). The current state of operation and material and technical support of heat and electricity production power plants in Ukraine is unsatisfactory, which is expressed by high volumes of harmful emissions into the environment (Kutsan and Yaroshevska 2002; Skibina 2014).

In 2015, Ukraine was ranked 111th among 129 other countries in the Energy Trilemma Index (energy sustainability index), which is calculated by the World Energy Council (WEC). Figure 1 shows the dynamics of changes in Ukraine's position in the Energy Trilemma Index rating (energy sustainability index) for 2013–2021. This WEC index is given to a country based on several

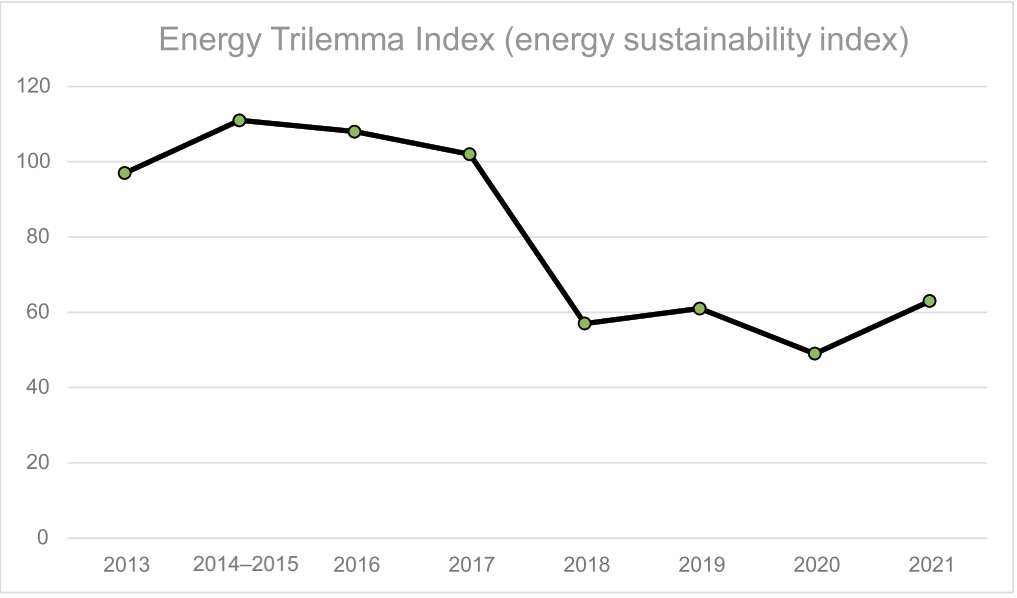

Fig. 1. Rating of the sustainability of the national energy policy for 2013–2021

Rys. 1. Ocena trwałości polityki energetycznej państwa w latach 2013–2021

indicators, namely: energy safety (energy security); accessibility of the produced energy for the population (energy equity); environmental sustainability of the energy sector (environmental sustainability). The index is given according to a rating from D to A for each factor. Ukraine's rating is B, C, and D. The worst situation is with the last factor, which is the environmental impact of production. In addition, there is some lack of electricity available for the households. Denmark, Switzerland, the United Kingdom, and Sweden received the highest rating, AAA (Denysyuk et al. 2016).

The social challenges of the Ukrainian energy sector include "bad habits" – non-transparent, shadowy, corrupt economic relations that are a heritage of centralized Soviet bureaucracy and, consequently, a low level of competition culture. These phenomena are still tolerated by society, including by industry experts, although such tolerance indirectly and in the long run is harmful to them as corruption and clientelism lead to the de-technologization of the industry, as well as to a decrease in its capitalization and investment attractiveness. It should be noted that due to the shortcomings of the monopoly operation of thermal power stations as a direct source of corporate income, the heat-energy sector as a whole is stagnating, which is expressed in the implementation of political and budgetary manipulations (Tynnyj 2020; About problems of... 2020). Such conditions make it impossible to conduct comprehensive reforms in the energy sector, and in general, hinder the development of the country's economy and human potential.

The energy strategy of Ukraine for the period until 2030 (2013), formed in 2012, has changed in recent years, resulting in the demonstration in 2017 of the Energy Strategy of Ukraine for the period until 2035 "Safety, Energy efficiency, Competitiveness" (2017). According to the declarations of this energy strategy program, the main task until 2025 is to save energy and ensure the development of an energy-efficient community. It is not the first time that the lifetime of all TPPs is planned to be extended until 2025, but the renewal of the capacities of the Ukrainian energy system is an urgent priority.

Until 2021, no regulatory documents in the energy sector mentioned such types of work as "energy management" and "energy audit". Energy management includes the planning and operation of energy production and energy consumption units as well as energy distribution and storage. An energy audit can clarify a company's energy consumption and identify areas for potential savings. However, at the end of 2021, the Law of Ukraine No. 1818-IX "On Energy Efficiency" (2021) was adopted, and these two concepts were finally defined. At heat-energy production facilities, certain energy-saving programs are developed to maintain the existing efficiency indicators in the operation of existing equipment or to make partial improvements that ultimately do not lead to significant changes in the amount of fuel and energy resources saved. Instead, more effective short- and long-term energy-saving plans should be based on systematic reviews and the corresponding regulatory requirements. Conducting an ESEE, especially in the context of the shortage of financial resources, will help to improve the performance of energy equipment or to replace it reasonably. The immediate tasks of the ESEE are to critically assess the efficiency of energy facilities based on objective data, identify factors of non-compliance with the criteria, justify targeted low-cost energy-saving measures, and present possible energy-saving measures for more capital-intensive recovery projects.

However, for the Ukrainian heat-energy sector, systematic approaches to energy audits have not become an alternative to the formal, secondary measures that are performed from time to time at TPSs (Pylypenko 2020). This situation is due to many reasons: a lack of clear understanding of the content of energy audit and the results that can be obtained; the biased attitude of TPS management to external assessment due to an opportunistic understanding of corporate interests; the technological complexity of TPPs as a specific industrial complex; a lack of unbiased specialists with experience in inspection of thermal power equipment; a lack of experience in large-scale scientific and technological research and implementation in modern Ukraine; a lack of a clear science-based methods for determining technological and operational energy losses; a lack of funding for comprehensive energy-saving programs. It should be noted that over the past twenty years, methods have been developed and numerous effective external audits of energy facilities of industrial and municipal enterprises have been conducted. These included the development of energy-efficiency measures with the assessment of the environmental performance of enterprises (Deshko et al. 2011).

Although they exist in certain forms, energy audits at existing TPSs are, to summarize the reports of corporate press services, a closed internal corporate process. In the absence of procedures for performing an environmental impact assessment at TPSs and rules of interaction between the contractor and the customer, the audit should be started after negotiations, the results of which should be outlined in the protocol to the work performance agreement. If the audit is required not as a formal procedure for reporting to regulatory agencies, but to find undisclosed savings reserves, the aforementioned protocol should reflect an agreed and approved audit process, taking into account the specifics of each facility. Only after the parties are convinced that the appropriate conditions for the audit are in place and that the requirements to be strictly followed are agreed upon, can the audit process and an external review be initiated.

Customers' motivations for external energy audits generally exist between two poles – proactive and conventional. Proactive motivation is the customer's direct interest in the audit to identify energy-saving reserves and plan appropriate energy-efficiency measures, with a request for data reliability, systematic analysis, and specific conclusions. The conventional, common motivation is to obtain data for reporting to state regulators or other monitoring entities to maintain status and reputation, sometimes to challenge the data of state inspections or, in the worst case, for money laundering reserves (Ng et al. 2021). For its part, a professional contractor meets the needs of a proactive customer. Therefore, there will be many expectations on his part, namely: the openness of the TPS management to prompt and meaningful communication, including on non-standard issues; guaranteed access to current and archived data on the audited object and the relevant instruments and measuring devices, the list of which is determined in advance; guaranteed access to energy equipment and premises, and the necessary technical support from the staff; openness of the staff to provide clarifying and explanatory information within their technical and official competencies.

Attention should be paid to the contractor's and the client's understanding of the terms and scope of confidentiality in the work process. Beyond the state regulations on access to information and, in particular, specific restrictions that may reflect the customer's trade se-

crets, for its confidentiality, the contractor shall fix the time of all actions in the process of data collection and, along with the customer, make sure that electronic means of data storage, processing and transmission are safe. To simplify the above-mentioned chronological accounting and, to indirectly ensure the need for openness and trust between the customer and the contractor, and to increase the efficiency of the analytical component of the energy audit, it is advisable to accompany the project with the procedure of monitoring and evaluation (M&E) of survey data. M&E is a standard element for the projects of Western countries that include work with data having separate staffing requirements. In the most general sense, to conduct M&E at the time of signing the work performance agreement, based on the results of discussions, it is necessary to form an electronic audit database with shared access for viewing by both parties, determine the procedure for its maintenance by the contractor (filling in data, displaying variables, outcomes, benchmarks, coding non-parametric variables, etc.), reserving and checking.

2.2. Recommendations for the development of energy-audit methodology for TPSs

The TPS energy audit involves the implementation of a wide range of research surveys, which is why, at the first stage, it is advisable to formulate and approve methodological tasks and a plan that will determine the organizational procedures for the survey and mechanisms for obtaining results for a particular TPS (Yevtukhov et al. 2019). The main task of technological research at TPSs is to identify the causes of the overconsumption of fuel (overburning). All data obtained during the inspection should be converted to a certain indicator, namely grams of fuel used per kilowatt-hour supplied. This is because it allows for an economic assessment of the efficiency and dynamism of energy combustion. At operating TPSs, the task of increasing their efficiency is solved according to the normative methodology for assessing the main technical and economic indicators developed by UNPO Energoprogress (GKD 34.09.103-96 1996). Despite its rationality, it does not specify measures aimed at eliminating heat losses. These losses are defined as constants in further calculations (Khortova 2011). The process of forming and ensuring the conditions necessary for the high-quality operation of TPSs should be based on the application of special methods with consideration to external factors, compliance, and recommendations (Dunaievska et al. 2022):

1. To divide conditionally the workshops into two groups. The first includes equipment for the thermodynamic cycle of the coolant in all aggregate states. Typical elements of this group include a steam generator with auxiliary equipment, a turbine unit with auxiliary equipment, a coolant regeneration system, etc. The second group includes the entire fuel pathway from storage to the removal of combustion products.

2. To develop a questionnaire and conduct a reconciliation (verification) of the systems under inspection.

3. To classify the technological components of TPSs and compile their lists, indicating their expected impact on the technical and economic performance of TPSs.

4. To classify probable energy flows of TPSs by various characteristics, revealing the current links between the elements of the classification.

5. To take into account the possible non-additivity of the components of energy balances and models based on energy balances when analyzing the relevant data.

6. A thermodynamically based approach to the inspection and assessment of quantitative and qualitative characteristics of energy efficiency should reflect the physical value of energy losses in the technological cycles of TPSs. The quality of the heat process can be determined by the level of its deviation from the ideal cycle, the quantitative component of which is direct energy losses. It is advisable to determine the specific values of energy losses in the energy balance of a heat and power facility based on their coefficients.

7. To classify specific energy efficiency indicators by categories, according to various factors, particularly thermodynamic (equipment efficiency), fuel (energy resource composition), technological (technical condition of equipment, operating conditions, cycle efficiency, etc.).

The systematization of the data obtained following this list reveals the causes of energy losses at different organizational, technical and operational levels of energy conversion/production, thus contributing to the development of measures to eliminate them. The methodological complexity of the ESEE lies in the uncertainty of the initial information, as a result of which, the quantitative relationship of some factors with energy efficiency indicators may require an additional interpretation. It is advisable to abandon simplifications based on the use of only TPS operating parameters (which record the actual efficiency coefficient under non-designed operating conditions) and apply operating criteria (coefficients or nominal variables), determining their statistics when comparing the performance of design modes and ideal cycles. For example, nominal and constant steam pressures which are found in the boiler unit and turbine condenser have a limited control range. The efficiency of implementing energy-saving measures in the heat- and electricity-production industry depends on the correctness of determining the actual technical and economic indicators. While the accuracy of the assessment of the perfection and quality of equipment operation modes depends on the reliability of the obtained data. This determines the professional, moral and ethical requirements for performers: the availability of appropriate qualifications, responsibility and integrity.

Assessment of the efficiency of Ukrainian TPSs or their particular subsystems should be performed using theoretical tools of statistical analysis (e.g. regression analysis to determine the relative magnitude of loss and savings factors, factor analysis to determine complex and hidden factors, unobvious savings reserves, etc.) and electronic tools for appropriate data processing, such as SPSS (Statistical Package for the Social Sciences) and R (statistical programming language R). The technical basis for effective analytical work within the framework of the ESEE is the ongoing implementation of the data-monitoring and evaluation procedure outlined at the end of the previous paragraph. M&E provides a structural organization of data suitable for use with electronic analysis tools, which has a positive impact on the speed and quality of results. In

addition, due to the use of M&E as a form of internal project control, the survey methodology can be adjusted by the Parties for rational reasons.

2.3. Sequence and procedure for conducting an energy audit

Following the customer's requirements, it is advisable to classify energy audits into different levels, such as: from initial, simplified to specific, comprehensive, and time-consuming. A simplified energy audit covers the following scope of services: general conclusions about the efficiency of energy production and consumption; providing standardized measures to ensure energy savings. A simplified energy audit is mainly focused on a marketing approach to create a proposal for the replacement of energy equipment. A comprehensive energy audit has three stages of implementation – preparation, main and final works.

Preparation includes solving organizational and technical issues, such as holding a workshop with the customer, drafting and approving questionnaires on statistical, documentary and technical information. Also included are: the visual inspection of equipment; the examination of regulatory, technological, and executive documentation; the formation of research objects into groups, etc.; analysis of the information received – checking the completeness of questionnaires and availability of provided copies of technical documentation, the completeness and reliability of which determines the quality of energy audit; the drafting and approval of the energy audit methodology. Compiling lists of reviewed objects of technological and heat process schemes characterized by a significant impact of their energy properties on the technical and economic factors of the TPS, and elements that have a lesser impact. Thus, the coordination of the schedule of surveys of the reviewed objects, with the definition of time intervals of the survey and the list of measurements to be carried out; determination of the scope, cost and terms of work with the subsequent conclusion of the agreement on the provision of energy survey services; final approval of the calendar plan with the customer; agreeing on the terms of confidentiality; determining the procedures for monitoring and evaluation of the survey data.

The main works include the inspection of the objects/elements of the study according to the calendar plan (visual inspections, measurements, surveys, etc.):

- analysis of the existing state of the equipment with the determination of the equipment`s energy-efficiency potential;
- the survey data should be reflected at least in an Excel spreadsheet, which is constantly updated; working with the data obtained requires strict adherence to the procedure for updating, storage and confidentiality;
- immediately after each of the above forms, lists and other reporting elements are completed, the relevant data is electronically sent to the project database;
- drawing up energy balances of the main and auxiliary systems, taking into account energy consumption for own needs; determining the causes of losses of input-energy resources in the process of heat production;

- analysis of the dynamics and quality of the results achieved through the implementation of previous energy efficiency measures;
- control of the correctness of data filling and entering it into the electronic project database, regular monitoring of the compliance of calculation formulas in the database tables;
- analysis, processing and coordination of the survey results with the customer; comparison of actual indicators with planned, rated, and designed, previous years' indicators and the best indicators in the industry;
- analysis of factors that affect the efficiency of equipment performance.

The results of the information analysis should be presented in the form of tables, diagrams, graphs, etc. If technical means are available (smartphone, tablet, mobile Internet) and the energy auditor complies with digital security standards (the survey form can be transferred to the database electronically, according to the procedure for controlling data transmission), this reduces the time for calculating energy balances, and preparing and approving an interim report. The completion works include: drafting and agreeing the conclusions on the efficiency of operation of TPS equipment and systems with the customer; developing economically feasible energy-saving measures; drafting the final report with detailed calculations, description of the methodology, reference data used, etc. The final report consists of several parts: an abstract – an independent document with a brief description of the results of the work for top management and non-technical specialists; the main part containing a description of the work performed; annexes to the report, which provide information that may be useful to the customer; a workshop with a presentation of the energy audit results available to the team.

The projected energy efficiency indicators set out in the reporting document are not unchangeable as they are statistical benchmarks. The report should reflect the factors that may affect the deviation of actual indicators from the projected values. The proposed energy-saving measures should consider the technical, economic and organizational specifics of the TPS. The components of the audit may constitute a separate subject of work performed by several specialists in different proportions but representing a certain useful integrity. These are: P1, which is the modelling of energy-saving measures based on data received on request or in open access; P2, which is the implementation and monitoring of primary (and specialized) energy-saving measures, a complex; P3, which is full energy and environmental support or upgrade of the enterprise/group of enterprises (Dunaievska et al. 2022). The recommended activities listed above are the components of each other in the order of mentioning: P1 → P2 → P3.

3. Discussion

Borzooei et al. (2020) studied the issue of assessing the efficiency of energy companies with a particular focus on the energy audit mechanism. The authors identified peculiarities that are typical for Ukrainian society in the study, particularly in the implementation of the

audit process. Thus, it was found that Ukrainian TPSs are characterized by many factors and elements that must be subjected to expert review. This should be done during the organization and direct implementation of the energy audit. In addition, this step is necessary for the formation of high-quality projects to improve the technical and economic performance of plants. The researchers in the work also proved the complexity and multidimensionality of the technical analysis process performed at TPSs. The authors argued that Ukraine has a rather narrow range of possibilities, which in turn is wide in developed countries. The authors of this paper agree with this position and argue that solving tasks related to energy saving can be achieved by establishing a connection and dependence between the level of energy consumption and endogenous and exogenous factors.

In addition, attention should be paid to the work of Volchyn et al. (2022), who also studied the experience and state of the Ukrainian heat- and electricity-production industry in the context of environmental reforms. In opinion, Ukraine in particular lacks high-quality and effectively controlled economic and monitoring components within the TPSs. The authors argue that the existing management approaches used to design and develop energy-saving policies are outdated and unable to meet the challenges of today. Another disadvantage of the energy audit implementation process in Ukraine is the small number of human resources. In this context, the researchers emphasize the need to encourage the development of technical staff, especially its representatives who possess experience in this field. The authors believe that the described shortcomings characterize the current state of Ukraine's heat-energy-production sector from the perspective of energy audits. The remark about the lack of professional staff is correct, since resolving this issue would allow a better-quality energy audit, in particular with the use of modern innovations and tools.

The ideas of Kuzior et al. (2021), managed to model a project aimed at developing Ukraine's heat-energy production sector and, accordingly, improving its technical and economic performance. Thus, this model is aimed at three vectors, namely educational, scientific and mechanical. The first is the development and implementation of a special training course called "General Principles of Energy Audit". To a greater extent, this course should be integrated into the educational process of students pursuing higher education in natural and technical specialties. As a result, it is expected that graduates of higher education institutions will be able to acquire not only basic but also special professional skills, particularly for the implementation of high-quality energy audits. With regard to the second component of the project, namely the scientific component, its content is revealed in the possibility of organizing various kinds of research at events by both teachers and students. The authors are aimed at addressing and resolving certain controversial issues. The mechanical vector of the project proposed by the researcher concerns the formation of a special national or even international center whose main purpose would be to implement energy management and improve energy audits. The authors believe that the proposed approach is a priority and will effectively and promptly improve the state of Ukraine's heat -energy production sector within a few years. Moreover, they propose to equip higher education institutions with special mechanisms, such as smart electricity meters, so that future specialists can interact with modern devices and use them in their future professional activities.

In turn, Hong et al. (2021) analyzed this issue in general, in particular, they disclosed approaches on the basis of which it is possible to solve energy-saving problems, thereby improving the technical and economic performance of the national economy. The researchers believe that the priority for the state today is to develop and encourage economic interest among various management entities to support and develop economic entities and their use of energy resources. Another necessary step towards improving technical and economic performance in the thermal-energy sector is to form a mechanism of modernized regional energy principles and requirements. Based on these elements, it would be possible to organize and conduct independent examinations aimed at identifying shortcomings in the field of energy saving. At the same time, the authors emphasize that this approach is a priority for all sectors, including not only regional governance but also public life, such as residential building maintenance.

The position of Sadeeq and Zeebaree (2021) was the next one studied by the authors, who drew attention to the urgent need to consolidate financial and legal responsibility. To a greater extent, these concerned persons, in particular those with managerial powers, implement them in the field of the heat energy production sector. Thus, M.A. Sadeeq and S. Zeebaree propose the introduction of stricter penalties for officials, heads of institutions and individuals who inefficiently use fuel and energy resources, in particular by abusing their rights. Special attention should be paid to thermal power stations, in particular to the management entities whose inefficient decisions and activities lead to a decrease in the technical and economic indicators at such facilities. Thus, the researchers draw attention to the personal responsibility of citizens for actions that negatively affect the overall state of the national thermal energy sector. In the authors' opinion, this approach makes it impossible to determine the scope of actions and powers realized by such persons. However, this idea is promising in the context of its future development and implementation.

Strielkowski et al. (2020) also paid attention to energy efficiency issues. The researchers in their paper established a link between energy efficiency and the energy security of the state. The authors noted that these elements are interconnected and play an important role in the formation and development of the country's energy system. In their opinion, improving energy efficiency, in particular within thermal power stations, significantly reduces the economic pressure on the demand for fuel and resources. It is important that the state of the country's heat-energy sector directly depends on its energy efficiency level. Based on this, the priority approach to reducing and eliminating risks to national energy security is to improve technical and economic indicators in the heat-energy sector. The authors believe that this can be realized by updating the material and technical base not only technically but also through the development of human resources. In the authors' opinion, this approach is key to improving the energy efficiency and profitability of certain thermal power stations.

Based on the review of scientific papers, it can be noted that the common approach of scientists is the desire to develop the national heat-energy-production sector. At the same time, the considered conclusions can be effectively used in the process of modelling qualitative ways of implementing state policy in this area. The positions of the researchers are similar to the initial ideas and prerequisites presented by the authors of this material, which indicates the unity of

views and approaches to winning this scientific and practical challenge. The relevance of this issue is also evident, as it is being studied by a significant number of scholars. At the same time, some of them express their ideas based on specific factors and peculiarities typical for Ukraine.

Conclusions

To develop a methodology for assessing the efficiency of Ukrainian thermal power stations, the paper outlines the characteristics of the current state of the heat-energy production industry and summarizes approaches to organizing energy audits of industrial and public infrastructure. The necessity of conducting a comprehensive energy audit of thermal power stations by external (independent) energy auditors as an alternative to less effective approaches to improving technical and economic indicators is substantiated. Based on the experience of energy audits, the general rules for customers and contractors of energy audits of TPSs are highlighted and the methodological methods and sequence of energy audits are disclosed; it is expected that the improvement of TPSs in Ukraine is possible provided that the level of transparency in this sector is increased and some principles of the monopoly and private management of such facilities are restructured.

The approaches of the concept of external energy assessment as a type of energy audit are considered necessary elements for the successful implementation of the principles of the energy strategy of Ukraine for the period until 2035 “Safety, Energy efficiency, Competitiveness”. The outlined concept of the ESEE meets the preconditions for preparing the energy sector of Ukraine, which is currently in a state of war, for a large-scale capacity upgrade, organizationally modelling, literally to the definition of the strategy: conditions for attracting the necessary investments, which should be based on specific reform plans, transparency, and excellence of legal, regulatory, and normative mechanisms in the industry. The introduction of an external on-site energy examination as an alternative to formal assessment and a corporate (internal) energy audit is an effective investment, as it provides honest and specific data on the priority of TPS equipment operation and enhances several favorable factors, namely the reduction of energy losses, increases in the efficiency and reliability of operation, and a reduction of the negative environmental impact. In addition, the ESEE helps to identify complex factors behind certain deficiencies and provides valid grounds for forecasting and determining the main areas of operation and rehabilitation of TPSs. In the broader socio-economic context, the ESEE helps to improve the reputation of the enterprise and its investment attractiveness. In the macro-social context, the ESEE is a necessary element in reducing the level of the negative impact of industry on the environment and the computerization of social production.

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Rezerwy na poprawę efektywności elektrowni cieplnych: zewnętrzne badanie energii na miejscu

Streszczenie

W artykule uporządkowano, w formie zaleceń, doświadczenia z przeprowadzania audytów energetycznych zakładów produkcyjnych i komunalnych. Celem analizy jest uzasadnienie kryteriów skutecznego audytu energetycznego dla elektrociepłowni. Przedmiotem opracowania jest treść formalna i regulacyjna takich kryteriów. Przedmiotem analizy (warunek konieczny obiektywizacji) jest systemowy związek kryteriów formalnych z efektywnością produkcji. Na podstawie doświadczeń z badań energetycznych zwrócono uwagę na ogólne wymagania dotyczące przedmiotów audytu energetycznego elektrowni cieplnych oraz zalecono ogólne podejścia i kolejność przeprowadzania audytu analitycznego. Uogólnia się, że odbudowa i usprawnienie elektrowni cieplnych jako elementów systemu energetycznego Ukrainy jest opłacalne pod warunkiem, że relacje między klientem a audytorem energetycznym są przejrzyste i otwarte. Z punktu widzenia zarządzania energią, Zewnętrzne badanie energetyczne na miejscu ocenia techniczną i ekonomiczną wydajność elektrowni cieplnych w szeroki, kompleksowy sposób, identyfikując braki i rezerwy, zapewniając prognozowanie i określając główne obszary działania elektrowni cieplnej oraz poprawiając reputację zakładu.

Słowa kluczowe: efektywność energetyczna, zużycie energii, modernizacja, audyt energetyczny, ekonomia