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IMPROVING THE SYSTEM OF DIAGNOSTICS OF ENERGY COMPANIES' COMPETITIVENESS

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Abstract

Development of solutions for increasing the competitiveness of the most important production infrastructure – in the first place, energy systems – becomes especially important at the slow transition from stagnation to the renewal of development. In these conditions, the generating companies' development challenges, which have no uncertainties, appear instead of exclusion than a rule. Solving the tasks related to the analysis of the possible increase of power generating companies' competitiveness, including the development of energy cogeneration systems, is incredibly complicated by the uncertainty of external environment changes when studying assessing competitiveness. These problems required creating methodological tools based on multidimensional statistical procedures, making it possible to determine the competitiveness level of power generating companies' business units. Based on the analysis of the calculation results, recommendations were developed for the modernization of cogeneration energy sources. The recommendations proposed for the management of the energy company assume the use of modern energy technologies that have high environmental and economic efficiency.

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Keywords: Electricity, competitiveness, analysis, statistics, development.

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1. Introduction

Its place in the technological chain determines the unique role of the economy's energy infrastructure as the final link in energy production, which directly interacts with energy consumption. This forms the energy infrastructure profile and largely determines its efficiency (Butler et al., 2018). Therefore, the energy infrastructure is charged with complex and responsible functions for maneuvering fuel and energy resources, both in time and in space, and the electric power industry gives it unity due to the wide interchangeability of various fuel types used for energy production, as well as for involvement of new sources in the energy balance using energy cogeneration technology (Scholten & Künneke, 2016). This becomes an essential circumstance in the transition to an innovative economy that requires reliable, maneuverable, and efficient energy supply (Mehigan, 2018).

The complexity of assessing the competitive advantages of cogeneration and the conditions for positioning in the energy market required the creation of a special methodological toolkit that makes it possible to determine the cogeneration energy sources competitive advantages of the power generating companies operating in the conditions of high competition on the part of renewable energy sources and distributed generation (Calderóna et al., 2019).

2. Problem Statement

The specificity of cogeneration energy sources positioning determines the place of their products on the territorial energy market. It consists of the fullest possible realization of the competitive advantages of cogeneration, which are revealed compared with the separate alternative production of electric and thermal energy at condensing power plants and in boiler houses (Morley et al., 2018).

It has been established that for the competitiveness of cogeneration energy sources assessing procedure, it is of particular importance to determine the maximum permissible levels of indicators, the excess or failure of which leads to the development of negative processes (McInerney & Bunn, 2019). It is important to note, that when diagnosing the competitiveness of a power generating company, it is very important to take into account the set of indicators reflecting its competitive capabilities, which allows one to determine the reasons for the decline in the level of competitiveness and to concentrate resources on the most important links of the power company management system, in order to address the priority tasks for realizing the competitive advantages of the power company (Zhang & Yang, 2019).

In the course of the study, the identification of specific risks that create economic uncertainty, which to the greatest extent affect the cogeneration development trends, was carried out. These include: 1) exogenous risks (economic status of the region, fuel and energy balance of the region, institutional environment, energy consumption, ecology); 2) endogenous risks, which, depending on the nature of their occurrence, are divided into two groups characterizing economic aspects (energy efficiency, depreciation of fixed assets, dependence of power generating companies on the use of imported equipment, etc.) and corporate finance (position of the company on the stock market, value of power generating companies, fixed asset formation, operating profit, accounts payable, receivables, investment attractiveness, etc.).

The analysis showed that energy cogeneration systems belong to cybernetic type complex artificial systems developing in specific conditions, which must be taken into account when forming and realizing

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the competitive advantages of cogeneration energy sources: 1) relative homogeneity of products (electrical and thermal energy); 2) high degree of energy resources and energy carriers interchangeability; 3) substantiality of the connecting links (power lines, heating networks); 4) continuity, and in most cases continuity in time of technological processes governed by certain physical and chemical laws; 5) impact on social and economic processes and natural environment; 6) special complexity of systems subject to the multitude and heterogeneity of interacting elements, as well as of material and information connections.

As a result of studying the theoretical foundations of the competitiveness of cogeneration, it has been established, that for the methodological support of the process of constructing strategic objectives in power generating companies operating in energy cogeneration systems, it is necessary to develop a specialized industry-specific methodological toolkit for assessing business processes in the field of cogeneration (Goldbach et al., 2018). Besides, the revealed multi-level specificity of the cogeneration energy sources positioning in the territorial energy market required the creation of a special methodology that takes into account the peculiarities of the energy cogeneration systems development, which made it possible to study the influence nature of activating the investment process conditions in energy cogeneration systems (Lombardi & Schwabe, 2017).

3. Research Questions

The most important research issues related to the methodological support of the development processes of power generating companies and increasing their competitiveness are:

1. How does the specificity of the cogeneration energy sources positioning determine their products' place on the territorial energy market?

2. What conditions, that influence the development of competitive advantages of cogeneration energy sources, determine the properties of energy cogeneration systems and are fundamental in the process of competitive development?

3. How to assess the level of competitiveness of a power generating company using multidimensional statistical procedures, taking into account the conditions of economic uncertainty and the peculiarities of the energy cogeneration systems development?

4. Purpose of the Study

The purpose of the research is to create a methodological instrument for information support of determining the cogeneration energy sources competitiveness level by studying the processes of competitive development of dynamically developing, cost-effective, and reliable cogeneration energy sources that are part of centralized and distributed cogeneration systems.

5. Research Methods

The system analysis provisions, whereby the general methodology concept of energy cogeneration systems competitive development is built, make the study's theoretical and methodological basis. The research specifics determined the application of the system approach. This approach makes it possible to

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timely and fully consider various factors that affect the level of competitiveness of cogeneration energy sources as a result of changes in the business environment. The multivariable data statistical analysis methods and modern methods for determining the economic efficiency of investments, business planning, expert assessments, and economic and mathematical modeling were used for solving some individual problems.

The diagnostics of a power generating company competitiveness is carried out using the developed methodology, including seven stages.

Stage 1. Statistical Indicators Identification and Risk Analysis. Within the initial stage, creating economic uncertainty specific risks, which have the greatest impact on the level of competitiveness, were identified (Domnikov et al., 2018). These include:

a) exogenous risks characterizing: economic state of the region, fuel and energy balance of the region, institutional environment, energy consumption, ecology;

b) endogenous risks, which are divided depending on the nature of their occurrence into two groups. 1. Risks characterizing the economic aspects of a power generating company: energy efficiency, wear of fixed assets, the dependence level of generating companies on the use of imported equipment. 2. Risks characterizing corporate finance: company's position on the stock market, value of a power generating company, investments in fixed assets, operating profit, accounts payable, receivables, and investment attractiveness.

Stage 2. Distribution of Indicators by Groups of Influence. This stage involves dividing the relevant indicators depending on their general semantic influence on a generating company's competitiveness level: direct dependence and inverse dependence.

The direct dependence indicators are characterized by a unidirectional trend between the changes in the indicator and the degree of risk corresponding to it, i.e. with an increase in the indicator's value, the level of risk also increases. In contrast, the inverse relationship indicators are determined by the multidirectional relationship between the changes in the indicator and the degree of risk corresponding to it, i.e. an increase in the value of such indicators shows the decrease of the corresponding risk degree.

The importance and the necessity of this stage is determined by the requirement for subsequent standardization of indicators: bringing the different measured quantities to some general comparability due to the presence of the so-called "distance in multidimensional space" (Ward, 1963).

As a result of the distribution of indicators by groups of influence, preparing a time series of indicative indicators is carried out. To do this, the generated database was programmatically linked with the indicative analysis algorithm, which made it possible to increase the accuracy of diagnostics results of the cogeneration energy sources competitiveness and process large amounts of information on each object in the time frame. Further, the entire set of obtained indicators was divided into indicative blocks, following the specifics of each indicative factor (Gordon, 1994).

Stage 3. Normalization of the Indicators Initial Data. Normalization is carried out according to the linear scaling formula, separately for indicators of direct and inverse dependence (Lance, 1967). In the first case, formula (1) is used to normalize the initial data:

$$X_j^{н} = \frac{X_j - X_{min}}{X_{max} - X_{min}}, \quad (1)$$

where $X_j^{н}$ - specific value of the actual value of j indicator;

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X_j - the actual value of the investigated j indicator;

X_{min} - the lowest value of the investigated j indicator for the entire analyzed statistical array;

X_{max} - the maximum value of the investigated j indicator for the entire analyzed statistical array;

j is an ordinal number of the indicator under study.

The inverse relationship indicators are specified using the formula (2), which is converted from the formula (1), taking into account the methodological features of the inverse relationship indicators:

$$X_j^{\text{н}} = \frac{X_{max} - X_j}{X_{max} - X_{min}}. \quad (2)$$

Stage 4. General Distribution of Normalized Data by Levels of Competitiveness. To assess the level of competitiveness, the distribution of normalized data over three groups of states is carried out: normal (*N*), transitional (*T*) and critical (*C*) levels of competitiveness. As the research has shown, the division into three groups is not objective enough in differentiating the qualitative state of the object, in addition, it does not allow a reliable calculation of the response value to any changes in the competitiveness level. Therefore, it was proposed to distinguish three additional levels with different situation assessing stages, both within the transitional group (levels *B*, *C*, *D*) and within the critical one (levels *E*, *F*, *G*) (Domnikov et al., 2019).

Below is a brief description of each competitiveness level of a power generating company.

The normal competitiveness level is characterized by either a complete absence or a weak influence of risks on the competitiveness level on the part of the external and internal environment. As a rule, related to this state risks are promptly preempted by a company management, as well as by modern market regulatory tools (Jardine & Sibson, 1971).

The state of the transitional level of competitiveness is characterized by a pre-crisis impact on the competitiveness level. The objects falling into this state, as a rule, have low energy efficiency indicators. Therefore, in this case, it is required to implement urgent and, as a rule, high-cost measures to minimize the emerging threats. Compliance with the principle of efficiency implies the use of only own company resources, which, in most cases, limits the final effect. The speed and significance of the transfer of risks to the next group increases significantly.

The state of the critical level is characterized by a significant weakening of competitiveness. The need to quickly overcome the impact of risks presupposes an urgent mobilization of own and attracted resources. Neutralization of endogenous risks belonging to this state is possible; however, there is no confidence in their minimization when managing exogenous threats. The cost of managing such risks increases significantly. The predominance of the risks of this condition in the general structure may indicate a significant loss of competitiveness.

Stage 5. Carrying out Calculations of State Boundaries. Conducting preliminary calculations to assess the values of changes in states boundaries for an indicative block of indicators. These preliminary calculations assume the calculation of the following values:

mathematical expectation (M_i) for each risk in each state in order to determine unit vectors of mathematical expectations for each state (where i is the ordinal number of the studied state of each risk, $i = \overline{1,4}$).

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unit vectors of the difference between each value of the indicator in each state and the corresponding mathematical expectation,$\left(X_j - M_i\right)$ as well as their transposed values$\left(\left(X_j - M_i\right)^T\right)$ (where j is the ordinal number of the indicator under study, $j=\overline{1,n}$).

covariance matrices for each state of objects:

$$S_i = \frac{1}{n-1} * \sum_{i=1}^{n}(X_n - M_i) * (X_n - M_i)^T, \qquad (3)$$

where S_i — the covariance matrix of i state of the object.

inverse covariance matrices (S_i^{-1}) for each state of objects.

sums of inverse matrices of boundary states of objects$\left((S_i^{-1}) + (S_{i+1}^{-1})\right)$.

determinants of covariance matrices for each state of an object($|S_i|$).

unit vectors of differences in mathematical expectations of boundary states of objects$(M_{i+1} - M_i)$ and their transposed meanings.

Stage 6. Calculation of Individual Boundaries of Changes in the State of Risks.

Determination of the values of the changes boundaries in the objects states is carried out according to the formula (4) on the basis of the Bayesian treatment, the essence of which is that "for a set of objects ... an object with parameters *X* should be referred to set *i,* if":

$$ln(c_i q_i) - 0.5 * ((X - M_i)^T * S_i^{-1} * (X - M_i) - ln|S_i|) - (ln(c_{i+1}q_{i+1}) - 0.5 * ((X - M_{i+1})^T * S_{i+1}^{-1} * (X - M_{i+1}) - ln|S_{i+1}|)) = 0, \qquad (4)$$

where *X* is variables vector in the common space of the objects under study;

M_i, M_{i+1} - mathematical expectations of *i* and (*i*+1) states;

S_i, S_{i+1} - covariance matrices of *i* and (*i*+1) states;

q_i, q_{i+1} - a priori probabilities of the appearance of objects from *i*, and (*i*+1) states;

c_i, c_{i+1} - prices of erroneous assignment of objects to *i* and (*i*+1) states.

The line passing through the centroids of *i* and (*i*+1) states with coordinates M_i and M_{i+1} will have the following form (Domnikov et al., 2019):

$$X = b * (M_{i+1} - M_i) + M_i, \qquad (5)$$

where *b* is the straight-line parameter.

Substituting formula (5) into formula (4), we obtain:

$$\ln(c_1 * q_1) - 0{,}5 * ((b * (M_{i+1} - M_i) + M_i - M_i)^T * S_i^{-1} * (b * (M_i - M_{i+1}) + M_i - M_i) - \ln|S_1|) - (\ln(c_{i+1} * q_{i+1}) - 0.5 * ((b * (M_{i+1} - M_i) + M_i - M_{i+1})^T) * S_{i+1}^{-1} * (b * (M_{i+1} - M_i) + M_i - M_{i+1}) - \ln|S_{i+1}|) = 0. \qquad (6)$$

After performing algebraic transformations with formula (6), we obtain the following standard type quadratic equation:

$$b^2 * A_1 + b * A_2 + A_3 = 0, \qquad (7)$$

whereA_1, A_2, A_3 - variables, and also

$$A_1 = 0.5 * (M_{i+1} - M_i)^T * (S_i^{-1} + S_{i+1}^{-1}) * (M_{i+1} - M_i), \qquad (8)$$

$$A_2 = (M_{i+1} - M_i)^T * S_{i+1}^{-1} * (M_{i+1} - M_i), \qquad (9)$$

$$A_3 = -0.5 * (M_{i+1} - M_i)^T * S_{i+1}^{-1} * (M_{i+1} - M_i) - \ln\frac{c_i * q_i}{c_{i+1} * q_{i+1}} + 0.5 * \ln\frac{|S_{i+1}|}{|S_i|}. \qquad (10)$$

However, due to the fact that values of the boundaries of changes in the states of objects always belong to the segment from zero to one, the quadratic equation root (7) b_0 must always meet the condition: $b_0 \in [0.1]$. Otherwise, equation (7) has no roots.

When these conditions are met, the vector of values of the boundaries of changes in the state of objects is determined by the following formula (11)):

$$X_0 = b_0 * (M_{i+1} - M_i) + M_i. \quad (11)$$

This unit vector finds the values of the boundaries for all objects under study only between states *i* and (i+1). Therefore, when analyzing more than two states, the study must be continued using a similar mathematical instrument for states (i+1) and (i+2), etc.

Stage 7. Competitiveness Rating. At the final stage, each business unit of the energy company is ranked by their competitiveness levels, which is done by assessing the character of the situation from normal to critical.

6. Findings

The methodological approach to the indicative analysis was tested using the case of diagnostics of cogeneration facilities of the power company T Plus, PJSC (T Plus: about company, 2020) in the context of its individual business units. This energy company was selected as an object for indicator analysis because its cogeneration energy sources competitiveness level largely determines the general direction of energy cogeneration systems development in the territorial energy market of the Ural region.

The T Plus, PJSC is the largest private Russian company operating in the cogeneration business. The energy company owns over 6% of the installed capacity of Russian power plants and is the leader in the heat supply market (8%). The energy company provides a stable and uninterrupted power supply in 16 regions of Russia. The T Plus, PJSC includes 52 thermal power plants and about 18,000 km of heat distribution networks (T Plus: about company, 2020).

As a result of the risks analysis affecting the power generating company competitiveness level, the necessary calculations were carried out in accordance with the developed methodology. The values of normalized threshold levels for each block of indicative indicators were obtained, allowing calculating the level of competitiveness of the power generating company as a whole and of its business units at the next stage (Table 1).

Table 1. Normalized Threshold Values

Indicative blocks of indicators	***1.* Threshold Level**					
	B	***C***	***D***	***E***	***F***	***G***
Energy generation	0.114	0.321	0.448	0.598	0.672	0.805
Energy transmission	0.097	0.321	0.392	0.438	0.565	0.811

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Energy market conditions	0.110	0.262	0.394	0.451	0.602	0.734
Energy efficiency	0.185	0.317	0.405	0.528	0.687	0.795
Reliability	0.338	0.495	0.601	0.693	0.752	0.911
Economy	0.393	0.474	0.573	0.704	0.856	0.929
Finances	0.359	0.424	0.578	0.638	0.706	0.833
Overall situation	0.228	0.373	0.484	0.578	0.691	0.831

In the course of the studies carried out using the statistical data presented in the corporate reporting of generating company PJSC T Plus for 2020, simulation calculations were carried out, which made it possible to obtain the following results.

The diagnostics results of the competitiveness of the power generating company PJSC T Plus showed (Table 2) the most critical situation of the Mari El and Chuvashia, the Mordovia and the Komi production branches, and the highest level of competitiveness in the Nizhny Novgorod, the Perm and the Sverdlovsk production branches.

Table 2. Results of Competitiveness Diagnostics of T Plus, JSC Subsidiaries

Subsidiary (heat and power plant)		**Indicative blocks of indicators**								
		Energy generation	**Energy transmission**	**Energy market conditions**	**Energy efficiency**	**Reliability**	**Economy**	**Finances**	**Overall situation**	**Rating**
Vladimirsky	*r*	0.364	0.425	0.306	0.568	0.593	0.512	0.629	0.499	6
	h	*C*	*D*	*C*	*E*	*C*	*D*	*D*	*D*	
Nizhegorodsky	*r*	0.308	0.156	0.348	0.521	0.569	0.424	0.528	0.407	3
	h	*B*	*B*	*C*	*D*	*C*	*C*	*C*	*C*	
Kirovsky	*r*	0.361	0.487	0.274	0.493	0.681	0.634	0.652	0.511	7
	h	*C*	*E*	*C*	*D*	*D*	*D*	*D*	*D*	
Mordovsky	*r*	0.334	0.384	0.582	0.713	0.805	0.732	0.872	0.633	11
	h	*C*	*C*	*F*	*F*	*F*	*E*	*F*	*E*	
Oreburgsky	*r*	0.283	0.393	0.317	0.426	0.587	0.534	0.495	0.433	4
	h	*B*	*D*	*C*	*D*	*D*	*C*	*C*	*C*	
Permsky	*r*	0.147	0.325	0.216	0.521	0.434	0.518	0.402	0.366	1
	h	*B*	*C*	*B*	*D*	*B*	*C*	*B*	*B*	
Samarsky	*r*	0.277	0.318	0.412	0.506	0.631	0.680	0.501	0.475	5
	h	*B*	*B*	*D*	*D*	*D*	*D*	*C*	*C*	
Saratovsky	*r*	0.536	0.520	0.358	0.595	0.733	0.432	0.616	0.545	9

	h	*D*	*E*	*C*	*E*	*E*	*B*	*D*	*C*	
Sverdlovsky	*r*	0.220	0.158	0.216	0.401	0.509	0.482	0.624	0.372	2
	h	*B*	*B*	*B*	*C*	*C*	*C*	*D*	*B*	
Udmurtsky	*r*	0.308	0.398	0.517	0.397	0.678	0.547	0.793	0.519	8
	h	*C*	*D*	*E*	*C*	*D*	*C*	*F*	*D*	
Ulyanovsky	*r*	0.617	0.523	0.544	0.433	0.793	0.504	0.934	0.621	10
	h	*E*	*E*	*E*	*D*	*F*	*C*	*G*	*E*	
Komi	*r*	0.625	0.549	0.571	0.678	0.853	0.917	0.958	0.735	13
	h	*E*	*F*	*E*	*E*	*F*	*G*	*G*	*F*	
Mari El and Chuvashia	*r*	0.531	0.648	0.735	0.702	0.793	0.811	0.906	0.732	12
	h	*D*	*F*	*F*	*F*	*F*	*E*	*G*	*F*	

Note: *r* – calculated value; *h* – current status.

The analysis of competitiveness results of the power generating company T Plus, PJSC showed the following. In order to increase the competitiveness level of the energy company business units, it is necessary to use more extensively modern technologies that have high environmental and economic efficiency. The following most significant solutions for modernization of generating capacities should be recommended: 1) implementation of investment projects for the construction of cogeneration gas turbine and combined cycle gas plants; 2) optimization of the generating capacities structure according to the criterion of minimal costs; 3) increase in the share of the capacity of cogeneration energy sources operating on solid fuels; 4) gradual, according to replacement, decommissioning of units that have exhausted their resource to low parameters of live steam; 5) reduction of the energy-technological dependence of new coal-fired cogeneration power plants on a specific coal grade; 6) the maximum possible use of renewable energy sources, as well as energy sources using local fuels, especially for isolated areas; 7) coverage of heat loads mainly by sources operating on the cogeneration principle; 8) increasing the reliability of gas supply to cogeneration energy sources because of their mono-fuel mode.

7. Conclusion

1. In the course of the study, a methodological approach to assessing the level of competitiveness of power generating companies was developed. A specific feature of this methodology is an analytical toolkit designed to study the factors and processes that affect cogeneration energy sources' competitiveness.

2. In the future, the main provisions of the presented methodological toolkit can become the basis for developing a mechanism for managing the competitiveness of energy companies in non-traditional renewable energy sources development and decentralized energy generation systems.

3. The research results make it possible to enhance the practical significance of the research topics and catalyze the interest of the energy business towards the fundamental scientific knowledge in the field of improving decision-making technology.

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