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Management of Sustainable Consumption of Energy Resources in the Conditions of Digital Transformation of the Industrial Complex

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ABSTRACT

The purpose of the article is to study the dynamics of volumes and stability of the structure of energy resource consumption at manufacturing enterprises, the analysis of the technical readiness of energy systems to implement the ideas of digital transformation. As the main research methods used in this article there are the method of dipole energy analysis to determine the priority of types of energy carriers, the method of graphical visualization of data to find the release points of values from the zone of relative stability, the method of classifying objects to assign products to a group of objects on the level of energy sustainability. The article analyzes the current trends in energy consumption with the determination of the vector of sustainable energy consumption and the parameters of reserves for improving energy efficiency; prioritized separate types of energy production of petrochemical plants; the types of products were classified according to the level of sustainability of energy consumption with the establishment of control points having emissions of values from the zone of relative stability and unproductive consumption of energy resources; the high technical readiness of energy systems of manufacturing industries to automate production processes with the subsequent development of digital technologies has been proved.

Keywords: Energy Efficiency; Sustainable Energy Consumption; Automated Metering of Energy Resources; Energy Resources; Dipole Energy Analysis
JEL Classifications: O14, D24, C41

1. INTRODUCTION

Energy saving in Russian industrial enterprises is one of the most urgent problems of improving the competitiveness of products. Manufacturing enterprises in the process of their activity acquires raw materials, materials, components and other material resources, which constitute up to 60% in the structure of costs for production and sale of products. However, due to the constant increase in energy costs, the most expensive resources are electric and thermal energy. The development and implementation of energy-saving technologies at the enterprises can significantly reduce energy costs and thereby have a positive impact on the technical and economic performance of production by reducing production costs, increasing the company's profitability and competitiveness.

The Russian energy strategy sets reducing the specific energy intensity of the gross domestic product the central goal. Achieving this goal is ensured through the implementation of energy saving measures, well-timed transition to new technical solutions, technological processes and optimization forms. The inefficient use of energy in Russia has created significant potential for energy and energy savings. In the development of energy saving, it is necessary to take into account the current state of progress, in particular the advantages of the transition to "Industry 4.0." In the context of the development of the digital economy, when decisions are made on the basis of objective data, even greater opportunities open up for energy saving. Moreover, according to experts, the electric power industry is currently the most prepared area for transplanting the ideas of the digital economy.

In Russian industry today, two key trends in resource conservation are being considered. The first involves the implementation of energy management, improving environmentalization through the use of the best available technologies (BAT) using digital capabilities, based on the experience of successfully implemented projects. The second trend is based on solutions at the intersection of energy and digitalization, including the market technologies of the National Technology Initiative Energynet, which involves the creation of intelligent energy, solutions for the distribution network. The main idea is to modernize the power grid complex at a fundamentally different technological level, involving close interaction with the IT sector.

In this regard, in order to create energy-saving industries with smart energy systems, it is necessary to analyze current trends in energy consumption with the determination of the vector of sustainable energy consumption and the parameters of reserves for improving energy efficiency.

2. LITERATURE REVIEW

The issues of sustainable consumption of energy resources by industrial enterprises are the subject of numerous works by foreign and domestic researchers. Interest in this subject is due to the importance of the development of energy-efficient production systems on the basis of the scientific knowledge derived principles and patterns, advances in information technology. The main directions of research in the field of the concept of sustainable consumption of energy resources in the context of the digitalization of the economy are determined by the works of the following scientists: Zheng et al. (2020) investigated resource efficiency using new technologies; Milchram et al. (2019) substantiated the role of institutional values in energy transformations; Gu et al. (2019) proposed an effective scheme for calculating and distributing energy capacity; Marzi et al. (2019) On the example of OPEC, they conducted a competency analysis of the promotion of energy efficiency projects in developing countries; Moktadir and Jabbour (2019) developed key factors for energy-efficient supply chains; Zhou and Chen (2019) predicted energy consumption based on a multiple decompositional approach; Lopes et al. (2019) identified trends and upcoming paradigms of energy systems; Soares and Horlings (2019) formed the role of energy initiatives in the production of green facilities; Mao et al. (2019) developed a model of green industrial growth between Europe and China on the basis of the energy consumption model; Wu (2019) proposed a mechanism for the development of the energy industry cluster in the new economy.

The issues of innovative development of energy networks of industries based on the integration of competitive enterprises are considered in the works of Shinkevich et al. (2016), Rajskaya et al. (2019). In order to determine the impact of energy consumption on the economy, Baz et al. (2019) established the relationship between energy consumption and economic growth by asymmetric analysis; Lindberg et al. (2019) investigated the structure of energy policy and the transition to sustainable development of the EU countries; Xu and Chen (2019) assessed the relationship between environmental management and the financial sustainability of the energy industry and identified linear and non-linear effects.

Malysheva et al. (2017), Shinkevich et al. (2018), Dyrdonova et al. (2018), Shinkevich et al. (2019) proposed directions to increase the competitiveness of manufacturing based on solutions for the implementation of energy-saving organizational technologies.

However, despite the presence of significant theoretical and methodological material, analytical data, there is a lack of research to solve the problem of sustainable energy consumption in the industrial complex, focused on the introduction of digital technologies.

The lack of completeness of scientific and practical knowledge and solutions in the field of the study does not allow us to objectively model the processes of managing energy-saving production systems, to take into account the specifics of technological processes, the possibility of using information systems.

3. DESCRIPTION OF THE STATISTICAL RESEARCH BASE

A key indicator of energy efficiency in the industrial sector is the generally accepted parameter of energy intensity of products, which characterizes the amount of energy for the purposes of the main and auxiliary technological processes. The share of industry in the structure of energy consumption in the Russian Federation is over 50%. At the same time, manufacturing industries are energy-intensive types of economic activity due to their specificity. At the enterprises of these productions, the potential for reducing the energy intensity of products can reach 40-45% of the existing volumes of energy resources consumption. On average, about 25% of energy resources are spent on technological needs in industrial organizations, while in manufacturing enterprises, the figure is 40-41% (Figure 1). Technological needs include the consumption of energy in plants for the extraction, processing, transformation of raw materials, as well as specialized vehicles for auxiliary technological purposes (Rosstat, 2020).

The main types of energy resources used in manufacturing industries depend on the nature of the process and, accordingly, on the type of production. Thus, there is about 50% of heat energy using for technological purposes and about 12% of heat energy using heating of industrial and other premises in the Russian manufacturing industry (Table 1). No less demanded production is coal (45% of the total cost of energy), other types of fuel (37%), electric energy (36%). Less than 20% of the total energy resources are spent by manufacturing enterprises on cold water (19%), oil products (6.9%), hot water (6.6%) (Rosstat, 2020).

Thus, the priority direction of the energy saving policy of manufacturing industries should be to reduce the specific consumption of primary thermal energy, coal and other fuels. The introduction of resource-saving technologies for the above types of energy will give the maximum effect of reducing the cost of production and increasing its competitiveness. Expensive electric energy cannot be excluded from the list of priorities, nor can we maximize the opportunities for obtaining secondary energy resources.

4. METHODS AND MODELS

To determine the priority of types of energy carriers and the vector of consumption of energy resources, we use the method of dipole energy analysis. The dipole analysis allows us to represent the energy intensity of the object in the form of a vector in the coordinates of the energy carriers "electric capacity N – heat capacity Q." In general terms, the full energy intensity vector includes three coordinates: electricity, heat, fuel. In our case, as in many other production processes, thermal energy and fuel are combined into one resource, since they are similar processes of heat generation during the movement of high-temperature flows. The spatial vector-dipole representation of energy consumption gives a visualization of the structure of resources in dynamics, their ratio in terms of choosing the optimal energy sources. To establish trends in the deviation of energy resource consumption from a given value, we use the standard deviation function, which allows us to estimate the standard deviation of a random variable (N, Q) relative to the mathematical expectation based on its dispersion. The coefficient of standard deviation from the optimal energy structure (S) is determined by the formula:

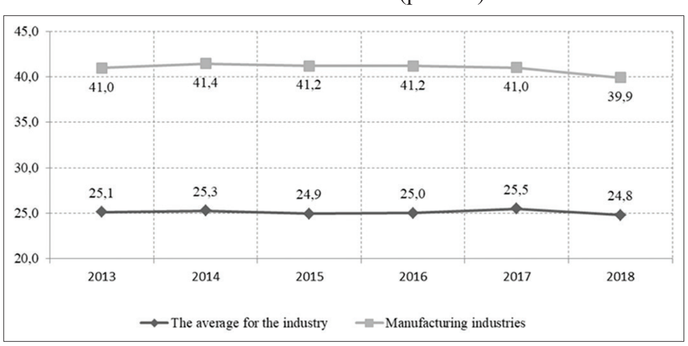
$$S = \sqrt{\frac{1}{n-1}\sum\nolimits_{i=1}^{n}(x_i - \overline{x})^2}$$

where x_i – the sample element, n – the sample size, x – arithmetic mean of the sample.

The calculation of the standard deviation coefficient allows us to make an assumption about the presence of unproductive expenditures of energy resources. The higher the standard deviation, the less stable the consumption of energy resources.

Implementation of these analysis methods is possible using the Microsoft Office Excel software product in the MS Office package or the Statistica software package.

Figure 1: The share of electricity consumption for technological needs in the total electricity consumption of industrial organizations of the Russian Federation (percent)



5. RESULTS AND DISCUSSIONS

An analysis of the database on the costs of processing industries for energy resources showed the importance of studying the dynamics of consumption of the main types of fuel and energy for production. In the selection process of the best available technologies, it is necessary to evaluate the existing reserves, clarify the structure of energy consumption, identify losses and prioritize the development of programs to increase energy efficiency and environmental production efficiency. A significant scale of energy consumption is characterized by technological installations used in the chemical and petrochemical industries. In the Russian Federation, this industry is assigned to category I, which is regulated by implementing the concept of introducing the best available technologies.

The method of vector or dipole energy analysis is used for the analysis of complex energy technology industries. The dipole diagrams (Figures 2-5) in the coordinates "electric capacity N - heat capacity Q" show the dynamics of the consumption of energy resources in 2012-2018. The object of research is energy-intensive products of petrochemical enterprises: synthetic resins and plastics, synthetic rubber, paint, varnish and lacquer, auto tires.

Table 1: Expenses for energy resources in the Russian Federation, bn. Rubles

Resource types	Energy costs in the economy	Energy costs in manufacturing	The share of manufacturing in the total cost of energy,%
Thermal energy (production needs)	159.2	78.8	49.5
Coal	350.3	157.7	45.0
Other types of fuel	291.0	107.6	37.0
Electric energy	1574.7	566.2	36.0
Natural and associated gas	1857.1	390.8	21.0
Cold water	117.2	22.3	19.0
Thermal energy (heating)	328.8	39.9	12.1
Petrochemical product	1693.7	116.6	6.9
Hot water	39.0	2.6	6.6

Figure 2: Dipole diagram of the energy intensity of the production of synthetic resins and plastics in the coordinates of "electric capacity - heat capacity"

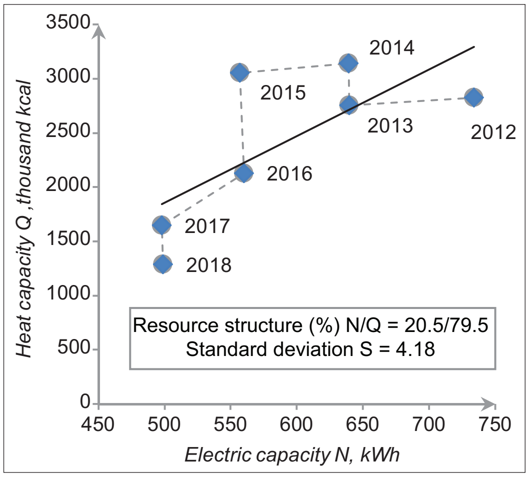


Figure 3: Dipole diagram of the energy intensity of synthetic rubber production in the coordinates "electric capacity - heat capacity"

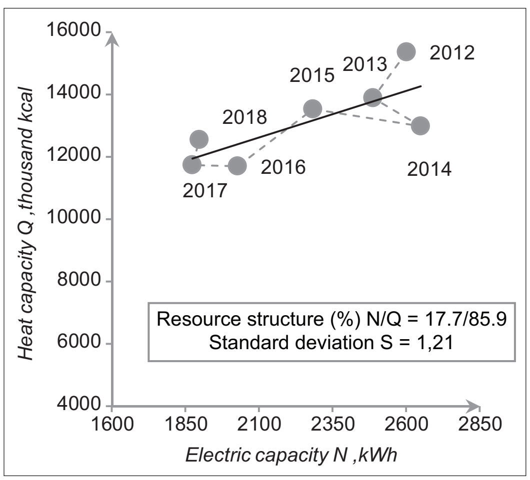
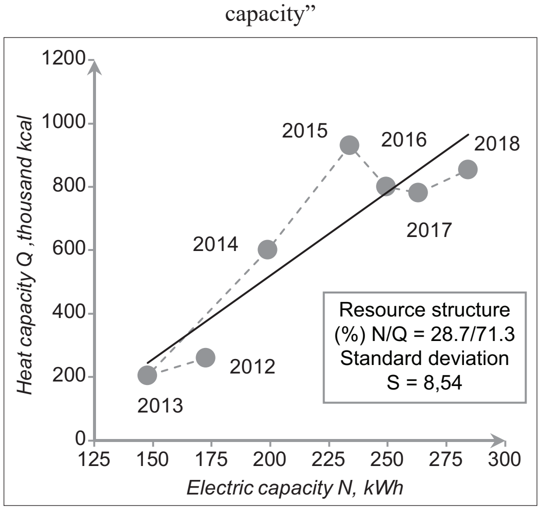
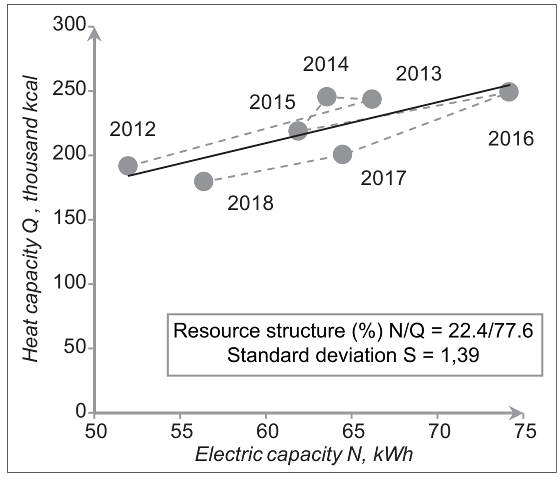


Figure 4: Dipole diagram of the energy intensity of the production of paint, varnish and lacquer in the coordinates "electric capacity - heat capacity"



The diagrams clearly demonstrate the priority of energy types. On average, the production of these types of products requires 78%

Figure 5: Dipole diagram of the energy intensity of the production of auto tires in the coordinates "electric capacity - heat capacity"



of heat energy and 22% of electricity, which explains the location of points on the diagrams in the upper part of the coordinate axis. The angle of the trend line determines the trend of deviation of energy resource consumption from the average value. The average value, ceteris paribus, is accepted as optimal, established by the technological regulations for the production of one or another type of product. For all kinds of products, without exception, in the dynamics of the last 7 years we can observe changes in the volume and structure of energy consumption. Consider the movement of the vector in the coordinate axis separately for the studied types of products.

An average of 20.5% of energy resources and 79.5% of thermal energy are consumed in the production of synthetic resins and plastics (N/Q = 20.5/79.5). For the period from 2012 to 2018, there is a significant reduction in energy consumption in absolute units: the rate of decrease in electric energy is 67.9%, the rate of decrease in thermal energy is 45.4%. Positive trend at first glance is partly due to some reduction in production volumes. At the same time, there is also an increase in the efficiency of the use of energy resources associated with the opening of new industries equipped with modern technological installations, power equipment, and the use of secondary energy sources. The coefficient of standard deviation from the optimal structure of energy resources for the study period was 4.18. Mostly, a structural change was noted in the direction of an increase in the share of thermal energy with a maximum emission from the zone of relative stability in 2014 (N/Q = 16.9/83.1) and in 2015 (N/Q = 15.4/84.6). These cases require additional study and, possibly, can be defined as unproductive or inefficient energy expenditures (Figure 2).

An average of 17.7% of energy resources and 85.9% of thermal energy are consumed in the production of synthetic rubber. (N/Q = 17.7/85.9). In this production we can also observe a slight decrease in energy consumption amid rising energy costs: electricity use decreased by 27% and heat energy by 28%. This is a positive trend in increasing energy efficiency of core companies in 2012-2016, which is due to the technical re-equipment of leading enterprises in the industry. The relatively stable dynamics of the indicators of resource consumption is accompanied by a practically unchanged structure of energy resources (standard deviation S = 1.21). In this regard, data on unproductive energy consumption in the production of synthetic rubber have not been identified.

A relatively unstable energy consumption is observed in the production of paint, varnish and lacquer. Firstly, during the period from 2013 to 2018, the increase in the use of electric energy amounted to 92%, the consumption of thermal energy increased by 4.2 times. Secondly, the structure of energy resources has changed significantly, where the share of electric energy decreased from 40% to 25%, respectively, with an increase in thermal energy from 60% to 75% (average resource structure N / Q = 28.7/71.3). The coefficient of standard deviation from the optimal structure of energy resources for the study period was 8.54. It should be noted that in 2016-2018, the reverse change in the above-described trend in the structure of energy resources was outlined - an increase in energy carriers and a decrease in heat carriers. The energy vector of the production of paint, varnish and lacquer undoubtedly requires additional research. However, according to available data, it can be assumed that there are overhead costs of thermal energy in 2014 (N/Q = 24.9/75.1) and in 2015 (N/Q = 20.1/79.9).

The analysis shows the comparative stability of energy consumption in the production of auto tires. In general, for the period 2012-2018, the change in the absolute volume of energy carriers is insignificant (the growth rate of electricity is 108.4%, the rate of decrease in heat energy is 93.8%), which may be due to fluctuations in market prices. With the optimal structure of the energy package N/Q = 22.4/77.6, the standard deviation coefficient for the study period was 1.39. However, a certain surge in energy consumption values can be observed in 2016, where with a constant structure within the established vector, there is a abrupt jump in consumption volumes of both electric and thermal energy. This situation, ceteris paribus can be viewed from the perspective of unproductive expenditure of energy resources. Thus, by establishing a conditional local scale of sustainability of energy resource consumption based on dipole energy analysis, it is possible to determine products that have zones or control points of unstable unproductive resource consumption. For the purposes of this study, we will adopt the following conditional scale of sustainability of energy consumption (the reference point is the time period):

- High sustainability of energy resources consumption - the absence of emission points of values from the zone of relative stability or the presence of no more than one control point
- Average sustainability of energy consumption - the presence of two to four control points from the relative values of ejection stability zone
- Low sustainability of energy consumption - the presence of four and more control points of ejection of values from the zone of relative stability.

Table 2 shows the classification of the studied types of products by the level of sustainability of energy consumption. The group of highly sustainable energy consumption includes the production of synthetic rubber and auto tires. The presence of a possible emission point of values from the zone of relative stability of auto tires requires a more detailed study of specific manufacturers and their energy consumption parameters.

The average sustainability of energy consumption includes the production of synthetic resins and plastics, paint, varnish and lacquer. In these cases, two control points are observed, having emissions of values from the zone of relative stability and, presumably, unproductive consumption of energy resources.

Instances of the group of low sustainability of energy consumption in this sample are absent.

Of course, the development of intelligent energy systems using digital technologies will allow us to quickly identify cases of inefficient use of energy resources and apply corrective actions to organize energy services at the enterprise. Improving the sustainability of energy consumption is possible by automating processes in accordance with the requirements of the "Industry 4.0" concept. As the processes of accounting and control of energy resources in industrial enterprises are automated, digital transformation of energy systems and the formation of a digital enterprise is possible. In this regard, the active movement of industrial production from automation of production systems to the formation of digital enterprise platforms is currently relevant.

For the purposes of automation and subsequent digitalization of energy industrial systems, first of all, it is necessary to equip production lines with energy metering devices. Russian manufacturing industries are best prepared for transplantation ideas of the digital economy. Energy metering devices are equipped with more than 90% accounting calculated points for all kinds of resources (Table 3).

Table 2: The results of the dipole analysis of the sustainability of energy consumption

Type of product	The optimal structure of energy resources (N/Q), %	The rate of growth (decrease) in energy consumption 2018/2012 (N/Q), %	The coefficient of standard deviation from the optimal structure of energy resources (S)	The level of sustainability of energy resource consumption (the presence of emission points of values from the zone of relative stability)
Synthetic resins and plastics	20.5/79.5	67.9/45.4	4.18	Medium (unproductive consumption of resources is possible in 2014, 2015)
Synthetic rubber	14.7/85.9	72.9/81.7	1.21	High
Paint, varnish and lacquer	28.7/71.3	192.5/415.9	8.54	Medium (unproductive consumption of resources is possible in 2014, 2015)
Auto tires	22.4/77.6	108.4/93.8	1.39	High (unproductive consumption of resources is possible in2016)

Table 3: Availability of energy metering devices at manufacturing enterprises of the Russian Federation in 2018

Resource type	Number of accounting calculated points of energy resources, units	Share of accounting calculated points, equipped with energy metering devices, %		Share of accounting calculated points, not equipped with energy metering devices, %	
		2018	2014	2018	2014
Electricity supply					
Electric energy	95478	96.5	96.5	3.5	3.5
Capacity	6556	98.6	98.7	1.4	1.3
Heat supply	16655	90.0	85.3	10.0	14.7
Water supply					
Hot water	8506	90.7	89.6	9.3	10.4
Cold water	32589	95.7	94.4	4.3	5.6
Gas supply	12901	97.3	97.0	2.7	3.0

They are most equipped with measuring instruments for the transmission line of electric energy, both in terms of energy consumption (96.5%) and in terms of accounting for electric power (98.6%). For this energy resource, the values of coverage of production by metering devices have been close to 100% since 2014. With such technical capabilities, the probability of enterprises switching to automated metering and energy consumption control is very high. A similar situation is observed with equipping organizations with gas consumption devices (97.3%).

Less rapidly, but with notable positive dynamics, carried out installation of technical means of control on communications for transfer of heat energy. At the end of 2018, the coverage of manufacturing industries with metering devices was 90%, which is 4.7 percentage points more than in 2014. Every tenth calculation point remains without metering and control of heat energy. A similar situation is observed in view of the consumption of hot water (90.7% in 2018). From 2014 equipment of metering devices of hot water consumption remained almost unchanged. The volume of use of cold water through measuring instruments is monitored at 95.7% of the required reference points (Rosstat, 2020).

Thus, at manufacturing enterprises, the level of equipping with devices for accounting and control of energy resources, exceeding 90%, allows automating the production process, increasing the accuracy of accounting for resources, and localizing places of energy losses. Monitoring and analysis of the database on energy consumption, identifying problem areas of the production chain make it possible to simulate a system for managing the efficiency of fuel and energy resources in a technological process in real time. At the same time, the enterprise's energy management model should include the calculation of the optimal energy efficiency regimes of technological facilities, to identify cause-and-effect relationships in the processes and determine the dynamics of the processes of energy consumption over time.

6. CONCLUSION

Thus, the study of dynamics of volume and structure of energy consumption of manufacturing industries leads to the following conclusions:

1. More than 40% of the energy resources of the Russian Federation account for the technological needs of manufacturing industries. Due to the specificity of technological chains and processes, the potential for reducing the energy intensity of processing industries can reach 45% of existing energy consumption. The main resource in the structure of the energy package of industrial enterprises is heat energy and fuel, which account for 62% and 45% of Russian resources, respectively. The priority direction of the energy saving policy of manufacturing industries should be the reduction of the specific consumption of primary heat and electricity, coal and other types of fuel
2. Using the method of dipole energy analysis we prioritized the types of energy carriers of individual products of petrochemical industries, where on average 78% is heat energy, 22% is electricity, control points for unstable or unproductive resource consumption are determined. The group with high sustainability of energy consumption includes the production of synthetic rubber and auto tires. The average sustainability of energy consumption includes the production of synthetic resins and plastics, paint, varnish and lacquer. In the second group there are two control points that have the emission from an area of relative stability and, presumably, unproductive consumption of energy resources
3. It is proved that manufacturing is the most prepared for the transplantation of the ideas of the digital economy, where more than 90% of accounting calculated points for all types of resources are equipped with energy metering devices. The most equipped with measuring instruments are communication on the transmission of electric energy (96.5%) and gas pipelines (97.3%). Less technical control coverage is observed on heat transmission lines (90%). With the current parameters of technical readiness of energy systems, manufacturing is a potential object for the automation of production processes with the subsequent development of digital technologies for monitoring and data analysis, modeling of production operating modes optimal for energy efficiency.

The research materials can be used in the development of software systems of smart energy systems that allow you to track the dynamics of energy consumption, determine the cause-effect relationships of deviations of resource consumption from a given trajectory, establish the optimal vector of sustainable energy consumption and parameters of reserves for improving energy efficiency.

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