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Article

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Computer Analysis of Energy and Resource Efficiency in the Context of Transformation of Petrochemical Supply Chains

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ABSTRACT

The purpose of this study is to identify areas of energy-efficient development in petrochemical supply chains through the use of computer analysis tools. The study uses system approach methods, comparisons, vertical dynamic analysis, economic and mathematical modeling, forecasting, factor analysis. Listed implementation methods helps to meet number of scientific results: systematized programs are applicable for petrochemical product supply management chains, as well as for a number of methods and algorithms developed by the authors in the framework of ensuring resource-saving development of petrochemical enterprises; dynamics assessment of supply chains' petrochemical products in terms of energy consumption and energy efficiency consumption indicators; a production function expressed in the form of dependence of the production energy efficiency between the factors of capital (Costs per 1 ruble of sold products) and labor (Labor intensity) is proposed, allowing rational planning in the parameters of the production and logistics system of the PJSC "Nizhnekamskneftekhim" enterprise; a factorial model is developed, as a result of which two factors (energy and economic) formed energy resource efficiency indicator of petrochemical supply chains is proposed. As a result, promising directions for reducing energy intensity production and improving of supply chains for petrochemical products energy efficiency are identified.

Keywords: Petrochemical Products, Supply Chains, Energy Resource Efficiency, Energy Saving, Energy Intensity of Production
JEL Classifications: O14, D24, C41

1. INTRODUCTION

The economy's petrochemical sector presents a particular interest to government bodies in the context of all levels of the country's economic system. This is due to high potential of sector's enterprises in terms of the production of competitive products as a result of deep processing of hydrocarbons. These products, in turn, are subject to sale in domestic and foreign markets and determine the volumes of the gross regional product and gross domestic product (Kvon et al., 2019). Thus, it seems obvious that it is necessary to analyze microeconomic systems that determine the importance of petrochemical enterprises efficiency increase and the economic development of the corresponding region. The effectiveness of their functioning is due to many factors, in particular energy.

In addition, during modern economic conditions - pandemics, falling oil prices, reduced activity of related industries and industries that consume petrochemical products - the strategic importance of resource consumption stregthens. Changes in the procedure for exporting products due to restrictive measures and, as a result, an increase in delivery times, significantly strengthens the role of logistics, that is also being an active consumer of microeconomic system energy resources.

The foregoing determines the feasibility for diagnosis of energy intensity and energy efficiency in petrochemical enterprise. We believe that the study of the activities of PJSC "Nizhnekamskneftekhim" - a major consumer of energy resources among petrochemical enterprises - may ensure the achievement of significant scientific results of practical interest. In this regard, the development of solutions set to improve subsystem of PJSC "Nizhnekamskneftekhim" production and logistics energy efficiency seems to be relevant.

Energy efficiency as a subject of research for many years has been a deep interest for domestic and foreign scientists. Approaches to the study of the issue are evolving, but the resulting aspect of energy consumption management is irreplaceable. A number of authors, in particular Shi et al. (2010), Bing and Rui (2011), Brunoroa et al. (2019), Locmelis et al. (2019), a team led by Farrou et al. (2020), explore energy conservation through a country-specific lens. Particular attention is paid to the study of chemical plants' energy efficiency Meshalkin (2009), Panarin and Meshalkin (2008), Meshalkin et al. (2019), Bobkov et al. (2018). The specifics of the use of renewable energy sources in the petrochemical industry are disclosed in a study by Dellano-Paz et al. (2015). The idea of using clean energy sources, taking into account the need to assess the social effect as a result of energy efficiency, is justified in the study by Dunlop (2019). Directions for rationalizing energy consumption, taking into account investment features, are presented in the works of Ayres et al. (2013). Ensuring energy savings within microeconomic systems is reflected in the works of Thiede et al. (2012), Brahmana and Ono (2020).

Despite the fact that production process is a key link in energy consumption industry, energy efficiency in the supply and transportation of products is also essential (Shinkevich et al., 2020). A number of scientific works are also devoted to the study of energy efficiency in supply chains, including the works of Kalenoja et al. (2011), demonstrating a system of indicators for assessing the energy efficiency of supply chains; Marchi and Zanoni (2017), who highlighted a methodological approach to energy management in supply chains and reflected a systematic view of improving energy efficiency.

The practical implementation of energy-efficient technologies is based on preliminary modeling and computer analysis of energy-efficient supply chains. So the issues of designing resource-saving processes in petrochemistry are also devoted to the works of Meshalkin et al. (1997), Moshev and Meshalkin (2014) and others.

At the same time, despite a wide range of scientific research in the field of improving energy efficiency, we consider it necessary to build economic and mathematical models that reflect the dependence between supply chain of petrochemical products economic efficiency energy factors and indicators at the microeconomic level.

2. DESCRIPTION OF DATA

Ensuring supply chains energy efficiency requires a systematic approach to the integration of a number of functional subsystems of an enterprise: production, logistics, information, etc. The solution to the problem is possible modernization of business processes organization in the supply chain, as well as automation and computer modeling. Currently, there are a number of programs that make it possible to implement logical-informational and economic-mathematical modeling of organizing production and supply chains processes.

Petrochemical supply chain management is often based on the IBM Decision Optimization Center (IBM) platform. The platform's functionality allows you to develop and implement highly effective planning and scenario modeling based on the principles of mathematical optimization. The IBM ILOG system is of practical interest due to the implementation of opportunities to reduce delivery costs, achieve reliability of supply, reliable operation of vehicles transporting petrochemical products, plan supply chain infrastructure, and optimize investments.

The core of the Decision Optimization Center is ILOG CPLEX, which performs mathematical optimization calculations. The CPLEX CP module facilitates task solutions such as constraint programming, tasks for optimizing scheduling and resource plans. CPLEX parameters are numerous, and they may be divided into the following categories: general parameters (algorithm selection, logging level, etc.), triggering and reprocessing, Simplex, Barrier and Network algorithm parameters, MIP parameters (integer tasks).

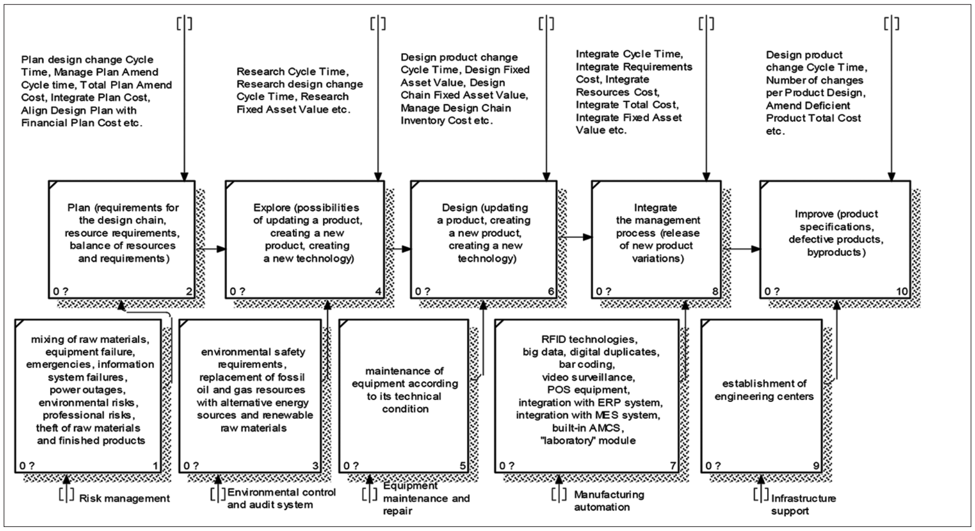
Also, supply chains energy efficiency is facilitated by rational management of information flows - a convenient visual view of data, a quick transition between numerous information directories. This is provided by means of visual programming Visual Basic for Application (VBA) of the MS Access environment.

Logical-informational modeling of production organization processes of a petrochemical complex may be considered within the framework of the IDEF notation languages. We propose the development of scientific and technical mechanism at petrochemical enterprise by synthesizing such organizational and technical solutions as resource-saving technologies, production automation, infrastructure support, DCOR-model and KPI system corresponding to auxiliary processes of the DCOR-model (Figure 1). The model is implemented by means of the All Fusion Process Modeler program (CASE tool BPwin).

The resulting model demonstrates how system, process or organization works. $IDEF_0$ models both supply chain organization processes and quality process models. It is a software tool for transforming an $IDEF_0$ model into a dynamic $IDEF_2$ model and executing it for modeling and supply chain management; software tool for converting $IDEF_0$ model to resource model; software tool for converting $IDEF_0$ model to organizational model.

In addition, supply chains energy-saving is facilitated by computer algorithms construction that provide economic and mathematical modeling using analytical programs Excel, Statistica. As part of the study, number of electronic resources were developed and registered.

Figure 1: Unified model of auxiliary processes for resource saving project preparation in the petrochemical industry

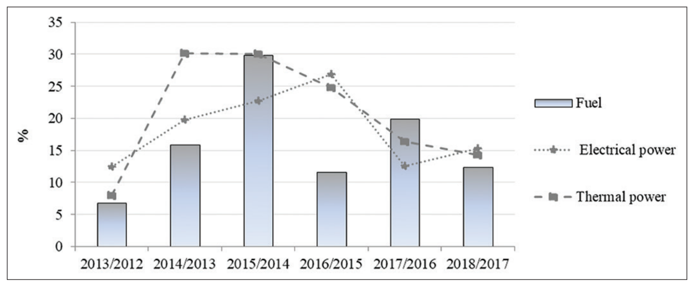


1. An algorithm for economic and statistical modeling of enterprises scientific and technological development is focused on resource conservation, which includes stages of constructing production function of innovative goods volume and services from the cost of capital and labor in science. The model was built in order to develop a mechanism for modeling resource conservation in the petrochemical industry
2. An algorithm for constructing a model of a resource-saving function using independent multicomponent variables adequate to the digital economy is based on production function that takes into account the digital specifics of capital and labor resources
3. Methodology for energy-resource-efficient reconstruction of an oil refinery based on pinch analysis takes into account external heat losses, containing a list of stages of the Pinch analysis and recommendations for the reconstruction of a chemical technology system using software products
4. Logical and informational models of business processes organization and production, and technological processes use the $IDEF_0$ methodology, reflecting the detailing of the production process based on the SCOR model.

For development of these provisions we consider it necessary to deepen the study of resource conservation issues towards efficient energy consumption within the framework of supply chain management for petrochemical products.

The study is based on performance results systematization of large petrochemical enterprise PJSC "Nizhnekamskneftekhim." First, prices analysis for energy resources used by the enterprise for 2012-2018 is carried out, since the structure of the enterprise's costs is determined by prices for resources (Figure 2). The price dynamics is unstable. The most noticeable jump in prices was recorded in 2015 for fuel, when the price increase was 29.93%. The overall picture is characterized by an increase in energy prices by 2017, which undoubtedly determined the structure and value of the enterprise's costs and becomes an objective reason for energy consumption rationalization in the supply chains of the company's petrochemical products.

Figure 2: Annual increase in energy prices in the supply chains of petrochemical products of PJSC "Nizhnekamskneftekhim"



Second, energy costs and energy intensity dynamics of petrochemical products production was assessed (Figure 3). There is a low dependence between the indicators: if in 2013 high values of energy consumption share in production costs and energy intensity were recorded, then in 2015 there was a clear gap between the indicators. On average, over the period under study, the rate of increase in energy consumption share was 0.45%, energy intensity - 0.28%. In general, for 2012-2017, energy consumption share remained practically unchanged - it increased by 2.39%, while energy intensity returned to the level of 0.13 rub./rub. Despite the enterprise implementation of a set of measures aimed at energy saving, it should be noted that there is an unrealized internal potential for resource-saving development: the production and logistics subsystem of the enterprise is capable of reducing the share of energy costs in the cost price to 17%, and energy consumption to 0.12 rubles./rub.

Third, cost structure assessment (Figure 4) revealed the prevailing share of heat energy consumption (53.2% in 2018). At the same time, the overall dynamics of energy resources for 2012-2018 decreased by 14% (or 8.6 percentage points), the share of fuel decreased slightly - by 2.8% (0.4 percentage points). This is due to the introduction of advanced energy-saving technologies, processes automation, restructuring of consumed energy resources towards electric energy the share of which increased from 24% in 2012 to 33% in 2018 (an increase of 37.5%).

Figure 3: Dynamics of prodcution energy costs and energy intensity of PJSC "Nizhnekamskneftekhim"

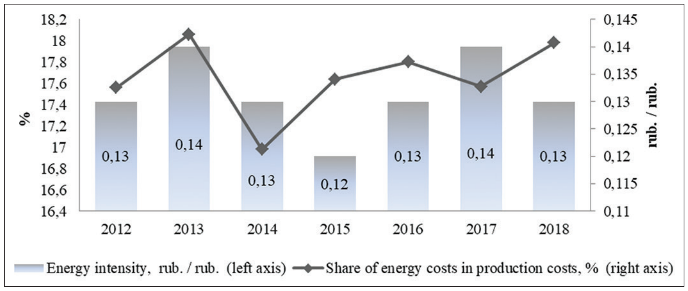
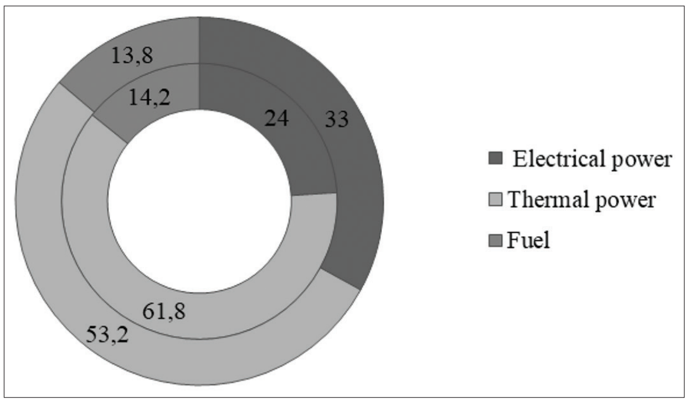


Figure 4: Structure dynamics of energy costs of PJSC "Nizhnekamskneftekhim", % (inner ring - 2012, outer ring - 2018)



Fourth, the economic indicators of PJSC "Nizhnekamskneftekhim" activity have been studied (Figure 5). When the cost of petrochemical products is steadily growing, then the return on costs, on the contrary, has an abrupt tendency to change. This is determined by the ratio of growth rate of profit and cost. In 2018, a positive change in indicator was recorded due to a significant increase in the company's profit - by 16369.80 million rubles.

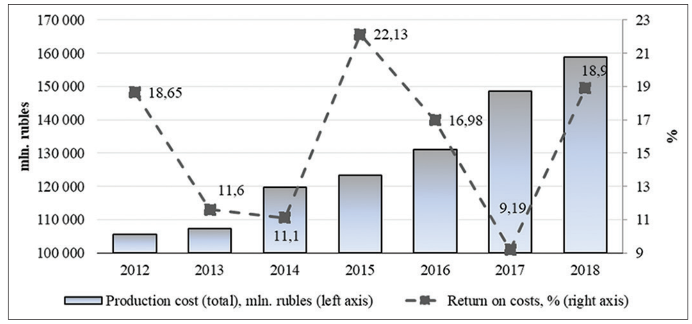
The presented analysis of economic indicators dynamics and energy efficiency indicators of PJSC "Nizhnekamskneftekhim" makes it possible to state an increase in prices for energy resources, which determines the costs growth for energy supply of the enterprise. The energy consumption share in the cost of petrochemical products is also growing, but there is a clear change in the consumed resources from thermal energy to electrical energy. The presence of unrealized internal potential for improving energy efficiency determines the relevance of computer analysis of energy factors and indicators of economic efficiency dependence in the production of petrochemical products.

3. METHODS AND MODELS

Computer analysis of energy and resource efficiency in petrochemical supply chains was implemented using economic and mathematical modeling, including:

1. The production function of Cobb-Douglas, which allows to formalize the mathematical dependence of energy efficiency on two factors - costs and labor intensity

Figure 5: Dynamics of economic indicators of PJSC "Nizhnekamskneftekhim", %



2. A predictive model that allows, based on the constructed production function, to determine the predicted values of energy productivity
3. Factor analysis, which allows classifying the indicators of enterprise development, taking into account energy efficiency.

The construction of an economic and mathematical model makes it possible to assess the dependence of an effective indicator on a number of independent variables. The classical production function describes the dependence between result on capital and labor investments. The two-factor Cobb-Douglas production function, taking into account adaptation to the subject of our study, has the form:

$$Y = a_0 * K^{a1} * L^{a2} \quad (1)$$

where Y is energy output (energy productivity), rubles/rubles,
K – costs for 1 rub. products sold (revenue), kopecks,
L – labor intensity,
a_0 – coefficient of neutral technical progress;
a_1 – coefficient of elasticity of factor K;
a_2 – coefficient of elasticity of factor L.

The construction of a production function is implemented by us using MS Excel tools and covers the following stages:

- Sequential logarithm of variables Y, K and L
- Implementation of the LINEST function, where the arguments are the logarithms of dependent and independent variables
- Assessment of deviations of calculated values $Y_{calc.}$ from actual $Y_{fact.}$
- Assessment of significance of the obtained production function according to the Fisher criterion: if the Fisher table criterion is exceeded over the calculated one, the adequacy of the constructed production function is stated with a probability of 95%.

Based on the constructed model, it is proposed to predict indicators by determining the trend values of independent variables and their substitution into the function of dependence of energy efficiency on capital and labor investments.

At the third stage, factor analysis is carried out, which makes it possible to classify by type a number of performance indicators of PJSC "Nizhnekamskneftekhim":

x_1 – costs for 1 rub. products sold (revenue), kopecks;
x_2 – energy costs,
x_3 – the share of energy costs in the cost price,
x_4 – return on costs,
x_5 – energy output (energy productivity),
x_6 – return on assets,
x_7 – labor intensity,
x_8 – coefficient of labor force acceptance,
x_9 – coefficient of retirement of labor.

Determination of number of factors is carried out on the basis of the Kaiser criterion - factors with an intrinsic value of more than 1. The selected indicators characterize development of related aspects of the enterprise and reflect the efficiency of not only the production system of the enterprise, but also the supply chains of the products manufactured by it. Since the construction of the model covers dissimilar indicators, the problem arises at different dimensions of variables. This problem is solved by standardizing the initial data, when the arithmetic mean of the normalized data is 0, and the variance is 1:

$$Y_{ij} = (x_{ij} – Xcp._j)/ S_j, \quad (2)$$

where Y_{ij} is the standardized value;
S_j is the sample variance of the j-th variable;
x_{ij} – initial values of variables;
$X_{cp.j}$ – the average value of the j-th variable.

Taking into account factor loads, it is proposed to introduce an indicator for assessing the energy and resource efficiency of petrochemical supply chains, which has the form:

$$I_{EESC} = \Sigma (Eig_i * F_i) \quad (3)$$

where i is the number of selected factors;
E_{igi} – eigenvalue of the i-th factor;
F_i is the actual value of the factor, calculated by the formula:

$$F_i = \Sigma (r_i * x_i), \quad (4)$$

where ri is the value of coefficient correlation between the variable and the selected factor;

xi is the actual value of the variable.

4. RESULTS AND DISCUSSIONS

A reliable economic and mathematical dependence of energy productivity on capital and labor costs has been built in the form of the Cobb-Douglas production function, which determines the leverage on the energy efficiency of petrochemical supply chains.

Rational energy efficiency management of petrochemical supply chains should take into account not only energy costs, but also a number of other factors. Undoubtedly, the functioning of the logistics system of an enterprise is affected by the efficiency of personnel, well-constructed routes for the movement of vehicles (both within the enterprise and with external links in the supply chain), facts of underload, which as a result affects the volume of fuel consumption. In this regard, we have selected indicators that reflect the capital and labor intensity of production of PJSC "Nizhnekamskneftekhim" for 2013-2018.

A model for managing energy output of petrochemical products production is proposed, presented in the form of a production function:

$$Y = 411,3*K^{-0,892}*L^{0,013},$$

where Y is energy output (energy productivity), rubles/rubles,
K – costs for 1 rub. products sold (revenue), kopecks,
L – labor intensity.

Evaluation of model according to Fisher's criterion includes a comparison between tabular and calculated values of the coefficients (Figure 6). Calculated value of the Fisher's F-criterion exceeds the tabular one:

F-criterion (calculated) = 9.85> F-criterion (tabular) = 9.55.

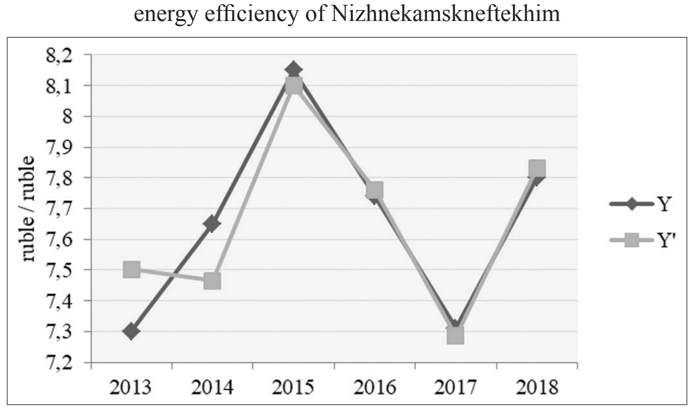
Thus, production energy efficiency is largely determined by unit costs level, since the coefficient of elasticity for this variable is higher than for labor intensity. It should be noted that the strong, but negative impact of unit costs indicates that energy efficiency will increase with additional costs.

A predictive model allows you to determine trends in energy productivity and tools to influence energy efficiency in order to increase it.

In order to predict the energy efficiency of supply chains for petrochemical products, a trend line of energy level output was built, taking into account the predictor variables K and L. Polynomials of the dependent and independent variables were constructed (Table 1) and a possible decrease in the energy output of production was revealed, all other things being equal.

Calculation of energy efficiency by substituting the predicted values of K and L into obtained production function confirms the negative trend in energy resources efficiency use by the PJSC "Nizhnekamskneftekhim" enterprise (Figure 7).

Figure 6: Deviation of the original data from the calculated value of energy efficiency of Nizhnekamskneftekhim



Thus, the constructed economic and mathematical model is a tool for managing energy efficiency of petrochemical supply chains. Despite the negative forecasts, we believe that the implementation of energy-saving programs by the enterprise will prevent the predicted decrease in energy efficiency. Also, despite the relatively low share of fuel in energy costs, it is necessary to focus on rational routing of supplies of products of PJSC "Nizhnekamskneftekhim."

The indicators of development of PJSC "Nizhnekamskneftekhim" were aggregated by factors that formed the basis for determining energy efficiency indicator of the supply chain of petrochemical products.

As a result of using the Statistica package (module - factor analysis), the variables x1-x9 are standardized according to formula (2) and aggregated by two factors (the optimal number of factors was identified by the Kaiser criterion). As a result, 2 types of variables were formed according to the principle of high factor loads: the energy factor, which combined the indicators of energy consumption and labor intensity of production, and the economic factor, which covers the indicator of the efficiency of management of the company's fixed assets and personnel (Table 2).

An inverse relationship was found between the energy factor FEN and variable costs per 1 ruble. revenue and labor intensity. Accordingly, the value of the energy factor FEN will grow with decrease in unit costs and decrease in labor intensity of operations (mainly due to the automation of processes). It is noteworthy that employee turnover rates have a positive effect on the economic factor of FEC. This relationship can be interpreted as the renewal of human resources, which brings an additional positive effect in the energy-saving of the production and logistics system.

Table 1: Predicting production function variables

Vtariable		Polynomial equation	Prognosis 2019	Prognosis 2020
Costs per 1 rub earnings	K	$y = 0{,}3137x^2 - 2{,}7445x + 91{,}959$	88,12	90,08
Labor intensity	L	$y = 0{,}0043x^2 - 0{,}2146x + 1{,}596$	0,30	0,15
Energy efficiency	Y	$y = -0{,}0539x^2 + 0{,}4081x + 7{,}048$	7,26	6,86

Table 2: Factor loadings of variables

Variables	Symbol	Energy factor (FEN)	Economic factor (FEC)
Costs per 1 rub. products sold	x_1	-0,837	-0,547
Energy costs	x_2	0,993	0,117
The share of energy costs in the prime cost	x_3	0,806	0,592
Return on costs	x_4	0,845	0,535
Energy efficiency (energy performance)	x_5	0,923	0,384
Fund profitability	x_6	0,370	0,929
Labor intensity	x_7	-0,879	-0,477
Labor force acceptance rate	x_8	0,695	0,719
Labor retirement rate	x_9	0,242	0,970
Expl.Var		5,355	3,645
Prp.Totl		0,595	0,405

The visual distribution of factor loads is shown in Figure 8.

Based on factors eigenvalues, we propose to formalize the dependence of the factors in the form of an indicator of the energy and resource efficiency of petrochemical supply chains. Since we take into account the total energy costs in the factor model, it is advisable to reduce the resulting indicator value by 100,000:

$$I_{EESC} = (7{,}96 * F_{EN} + 1{,}03 * F_{EC}) / 100\ 000,$$
$$I_{EESC\ (2014)} = 1{,}37,$$
$$I_{EESC\ (2018)} = 0{,}29.$$

The use of indicator in practice also allows one to judge about the decrease in energy efficiency of PJSC "Nizhnekamskneftekhim." In this regard, we believe that the models we have proposed reflect the latent relationships between the private indicators of enterprise's performance and are practically significant sets of variables, a systematic approach to managing allowing the enterprise to minimize the impact of external factors and stabilize energy efficiency of the production and logistics system.

Figure 7: Predicting energy efficiency (2019-2020) by applying a production function

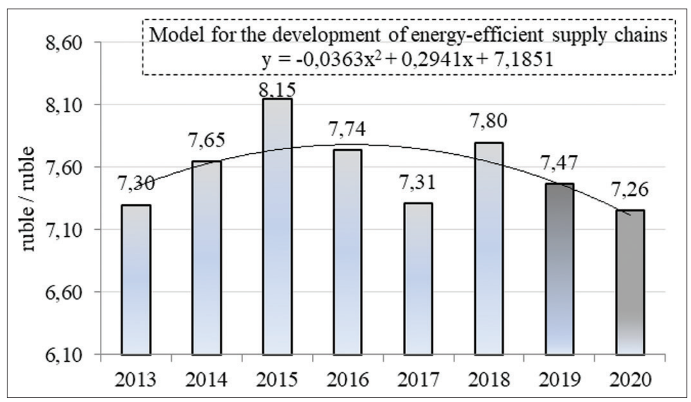
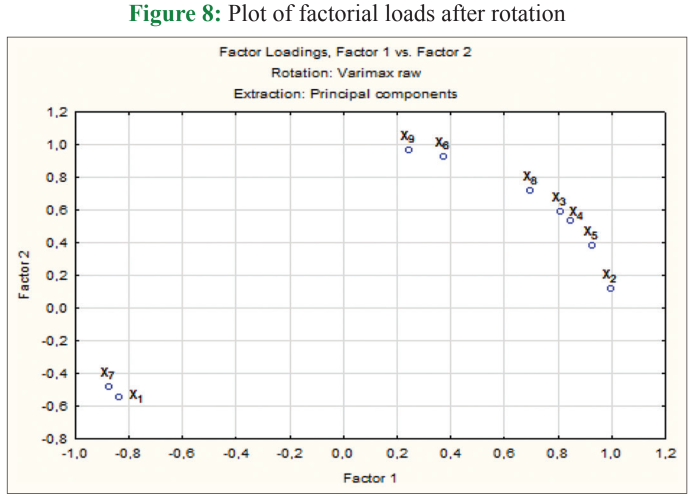


Figure 8: Plot of factorial loads after rotation



5. CONCLUSION

Diagnostics of energy consumption by production and logistics system of PJSC "Nizhnekamskneftekhim" revealed ambiguous trends in implementation of the energy saving policy. Despite this, it should be emphasized that the company's achievements in curbing energy consumption in the context of stable price increases. Currently, a key factor in development of the enterprise is the impact of the current crisis situation on production - a sharp drop in demand for some types of petrochemical products, at the same time, a sharp increase in demand for disinfectants. The performance of petrochemical supply chains spanning links from other regions is under attack due to restrictions on interregional transportation. It is possible to overcome the destabilization of enterprise development by adapting production, assortment policy and organizing supplies to crisis phenomena to restructuring demand. Accordingly, a modernized (taking into account these changes) approach to energy conservation of production and logistics system is required. As regards to the transport subsystem, it is important to observe the rule of efficient loading and optimal routes. The indicated, undoubtedly, is of interest for future scientific research.

An analytical review of research works of domestic and foreign scientists, the subject of which is energy conservation, made it possible to reveal the poor knowledge of the interdependence between energy and economic factors at the microeconomic level. When assessing the energy and resource efficiency of the petrochemical supply chain, we took into account not only the production system of the PJSC Nizhnekamskneftekhim enterprise, but also the logistics aspect. In particular, we are talking about the transportation of petrochemical products and fuel costs for transportation, which directly affects the energy efficiency of the supply chain.

We believe that the adaptation of production and logistics system of PJSC "Nizhnekamskneftekhim" to global economic challenges necessitates continuous improvement of managing energy consumption mechanism and solving a number of organizational, economic and technological problems. The tools for improving this mechanism are proposed in this study and are reduced to the possibilities of forecasting and managing the energy and resource efficiency of petrochemical supply chain based on:

- The production function, expressed as the dependence of the energy output of production on the cost per 1 ruble. revenue and labor intensity of production
- Factor model and the proposed indicator of energy resource efficiency of petrochemical supply chains.

In our opinion, the practical application of conducted computer analysis results will help to identify the internal unrealized potential of energy efficiency in the supply chain of petrochemical products, and to ensure the competitiveness of products in the global petrochemical market.

6. ACKNOWLEDGMENTS

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