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Forecasting the Energy Capacity of Petrochemical Productions Under Conditions of Technological Transformations

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ABSTRACT

The purpose of the study is to identify patterns of energy-saving development of the petrochemical industry in the context of the introduction of innovations and to predict the energy intensity of the industry based on economic and mathematical modeling. As part of achieving the goal, an analysis of the series of dynamics was carried out and prognostic methods based on variant correlation analysis and regression modeling were applied. At the first stage of the study, the dynamics of energy consumption and costs of innovative activities in the development of petrochemical industries in Russia was assessed; at the second stage, a predictive model of changes in the energy intensity of petrochemical industries was built. As a result of the study, the regularities of the development of petrochemical industries in Russia were revealed (stable reduction in energy consumption, unstable dynamics of unit costs for innovative activities of petrochemical industries); the nature of the influence of technological modernization of production on the level of energy intensity is determined, which is manifested in the difference in sectoral accents of innovative development; regression equations are proposed, reflecting the dependence of the energy intensity of petrochemical industries on the volume of sales of industry products; calculated the predicted values of energy intensity, allowing to develop a set of management measures to support the energy efficient development of industry in Russia. The formulated conclusions and results can serve as a basis for improving the strategic directions of development of the petrochemical industry in Russia, taking into account the prioritization of the implementation of energy-saving innovative solutions.

Keywords: Petrochemical production, Energy intensity, Technological transformation, Innovation, Russia, Forecasting
JEL Classifications: C21, L60, O14, Q43

1. INTRODUCTION

The working of industrial enterprises which focused on energy and resource saving are aimed at the implementation of innovative projects which designated as priorities in the context of technological transformation. Based on the principles of energy and resource saving production systems, it becomes possible to achieve maximum results from the introduction of new technologies: reduction of waste; processing of products and materials in order to increase the sustainability of the enterprise; optimization of resources and resource consumption through their reuse.

The problem of energy saving industry development is one of the most important problem of modern economy, on the solution of which the efforts of the world community are focused. Energy is intertwined with political views, economic issues, social responsibility to society, and is the "nervous system" of the global organism.

The lack of systematic management of current and investment costs related to energy efficiency is one of the key factors hindering the implementation of government energy conservation policies in the industrial enterprise. Also, regulatory and legal acts need to be improved to ensure the effective implementation of management decisions to reduce energy consumption.

This problem field and the solution of the corresponding tasks are determined by the Energy Strategy of the Russian Federation for the period up to 2035. This document sets out the goal of innovative development and technological modernization of the fuel and energy complex of Russia and related industries, as well as improving energy efficiency indicators. The Strategy for Scientific and Technological Development of the Russian Federation, which provides for the creation of favorable conditions for innovative activities and for the generation of development projects in demand by industry, establishes a related development vector.

The relevance of the problem under study is unconditional, which reinforces the interest in the study of trends in the consumption of energy resources in the petrochemical industry.

2. LITERATURE REVIEW

Energy intensity is driven by technological progress, such as the use of more efficient production technologies and newer types of capital equipment (technological effects) and changes in the structure of the economy (structural effects). Special attention to the study of energy efficiency and energy saving of industrial production is given in scientific researches of Meshalkin et al. (2019), Shinkevich (2020), Shinkevich et al. (2019; 2020; 2021). Analysis of the state and development trends of industrial enterprises - consumers of energy resources, implementing the energy saving policy, analysis of the practice of energy consumption management using energy service contracts and the development of a conceptual model for organizing energy consumption management of industrial enterprises is presented in studies by Verstina and Meshcheryakova (2015), Galeeva et al. (2018).

Yildirim et al. (2019) researched energy consumption and economic growth for the BRICS-T countries, Cucchiella et al. (2017) has compiled a rating of European countries in terms of energy consumption in industry based on integral indices of environmental use and carbon footprint. Lin and Wang (2019) considered the possibilities of separate development of energy consumption from economic growth. Fotis and Polemis (2018) conducted research in the field of sustainable development, environmental policy and the use of renewable energy sources. Hengyun and Les (2012) in their scientific works investigate the issues of assessing the impact of energy intensity on the efficiency of industry and the economy as a whole.

The issues of increasing productivity in industry using energy conservation policies, analysis of barriers and factors contributing to a decrease in energy intensity in conditions of limited resources, the role of environmentally friendly technologies are considered in the study of Brown et al., (2011). They also highlight the benefits of energy efficiency in terms of environmental protection, safety and competitiveness. Huang et al., (2017) pay special attention to assessing the impact of technological factors on energy intensity, including research and development, and analyzing the side effects of technologies due to openness in the form of foreign direct investment. Directions of rationalization of energy consumption taking into account investment features are disclosed in the works of Ayres et al. (2013). Huang et al. (2017) in their research examines the issues of identifying the driving forces of energy intensity using the example of China. Their analysis shows that technological progress plays a dominant role in reducing the overall energy intensity of China.

The issues of influence on the development of energy infrastructure of such key factors as decarbonization, digitalization and decentralization are considered in the study by Silvestre et al. (2018). Dogaru (2020) analyzes the challenges and opportunities for technological innovation caused by Industry 4.0. It is also noted that the fourth industrial revolution attaches particular importance to the field of energy, in particular the development of clean and renewable energy sources through waste-free technologies, as well as the integration of renewable energy sources into the smart common grid.

Thus, in the scientific literature, issues of energy conservation and energy intensity in industry in the context of digitalization and technological transformations are considered from different points of view. At the same time, we consider it necessary to build economic and mathematical models that allow forecasting a decrease in the energy consumption of petrochemical industries in the context of technological modernization.

3. MATERIALS AND METHODS

The purpose of the study is to predict the energy intensity of petrochemical industries in the context of technological modernization. The achievement of the goal was facilitated by the solution of two key tasks:

- To study the dynamics of energy and innovation costs in the development of petrochemical industries in Russia
- To build a predictive model of changes in the energy consumption of petrochemical industries.

The study is based on the use of a set of statistical and economic-mathematical methods, in particular:

1. Analysis of the series of dynamics, which allows identifying a trend, comparing the general trend and identifying patterns of innovative and energy-saving development of petrochemical industries
2. Predictive methods based on variant correlation analysis and regression modeling, allowing to develop a vision of energy-saving development of the petrochemical industry.

The data published on the Rosstat (2020) website served as the source of information for analyzing the series of dynamics and modeling. These are data on two types of production - chemical and production of coke and petroleum products - for 2006–2019, characterizing the costs of technological innovations (process and product), the volume of sales of industry products and the balance of energy resources (Table 1). The initial data formed the basis for calculating unit costs.

Energy intensity is defined as the ratio of the total consumption of energy resources (natural fuel, fuel processing products, heat and electricity) to the total volume of products shipped in the industry.

Table 1: Data for the analysis of petrochemical industries energy intensity in the context of innovative development (Rosstat, 2020)

Year	Energy consumption, mln tonnes of oil equivalent	Cost of technological innovation (mln rub.)	The volume of shipped goods of own production, works and services performed on their own (bln rub.)
		Manufacture of chemical products	
2006	64,3	25193,2	764,3
2007	35,1	22484,9	944,965
2008	32,5	32258,7	1312,181
2009	36,3	26061,2	1061,672
2010	39,6	23107,1	1427,273
2011	38,1	28407,1	1812,752
2012	38,5	36527,5	1941,784
2013	36,3	62941,1	1886,216
2014	36,2	56865,8	2102,321
2015	37,4	42752,2	2766,834
2016	37,7	35802,1	2553,786
2017	38,9	47854	2742,593
2018	38,5	67103,6	3265,833
2019	39,9	68586,2	3280,446
	Manufacture of coke and refined petroleum products		
2006	54,2	10204,3	2002,26
2007	34,5	14510,6	2277,115
2008	35,2	16822,2	2983,695
2009	35,5	32660,1	2661,537
2010	38,5	44261,9	3522,173
2011	40,6	85891,6	4553,721
2012	42,7	103052,2	5219,117
2013	48,2	193705,1	6030,711
2014	46,1	209874,1	6848,027
2015	45,3	139664,4	7061,093
2016	41,9	112400,2	6818,169
2017	45,6	166969,4	8202,805
2018	46,6	123014,9	10397,42
2019	50,8	140265,9	10253,62

The decrease in the indicator is a reflection of the energy-efficient development of the industry.

Unit costs for innovative activities are calculated as the ratio of costs for technological innovations (process and product) to the total volume of products shipped in the industry. The increase in the indicator is assessed as an increase in innovative activity at the enterprises of the industry.

The evaluation of regression models was carried out according to three key criteria - the coefficient of determination (a strong relationship between the variables of the regression equation, exceeding 90%); F-Fisher's criterion, which determines the adequacy of the regression equation to actual observations; Student's t-criterion, reflecting the significance of the coefficients of the regression equation (the significance of P should not exceed 5%).

4. RESULTS AND DISCUSSION

4.1. Patterns of Development of Petrochemical Industries in Russia in the Context of Energy Consumption

Innovative solutions cover not only the improvement of products, but also the modernization of equipment, technologies, processes, which, as a result, contributes to the leveling of various kinds of risks and energy and resource saving. Due to the specifics of production systems, there are obvious differences in the level and dynamics of innovative activity of industrial enterprises and the nature of energy consumption. These differences were studied using the example of petrochemical industries. In general, there is a prevalence of innovative activity in chemical industries - at the end of 2019, unit costs for technological innovations amounted to 20.9 rubles per 1000 rubles of chemical products sold; in the case of the production of coke and petroleum products, the value of 13.68 rubles was recorded per 1000 rubles of products sold. At the same time, in the second case, positive dynamics is clearly expressed over a number of years. In the case of the production of chemical products, unit costs for innovative activities in 2006-2019 decreased by 36.57% (Figure 1), in the case of the production of coke and petroleum products, on the contrary, they increased by 168.42%, that is, 2.7 times (Figure 2).

The indicated patterns, of course, affect the energy consumption of industries: in the first case, the energy consumption decreased by 85.5% and in 2019 amounted to 0.01216 tons of standard fuel per 1000 rubles of chemical products sold (Figure 1), in the second case - by 81, 7% and in 2019 amounted to 0.00495 tons of standard fuel per 1000 rubles of sales of coke and petroleum products (Figure 2). Nevertheless, the dynamics of energy intensity in industry is characterized as positive: the average growth rate of the indicator for 2006-2019 in both types of industries is

Figure 1: Dynamics of energy intensity and costs of technological innovation in chemical industries (built by the authors)

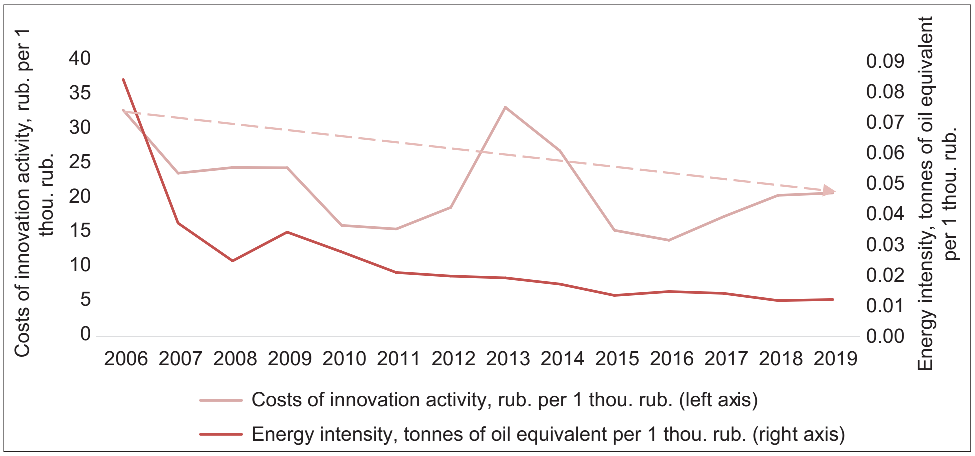
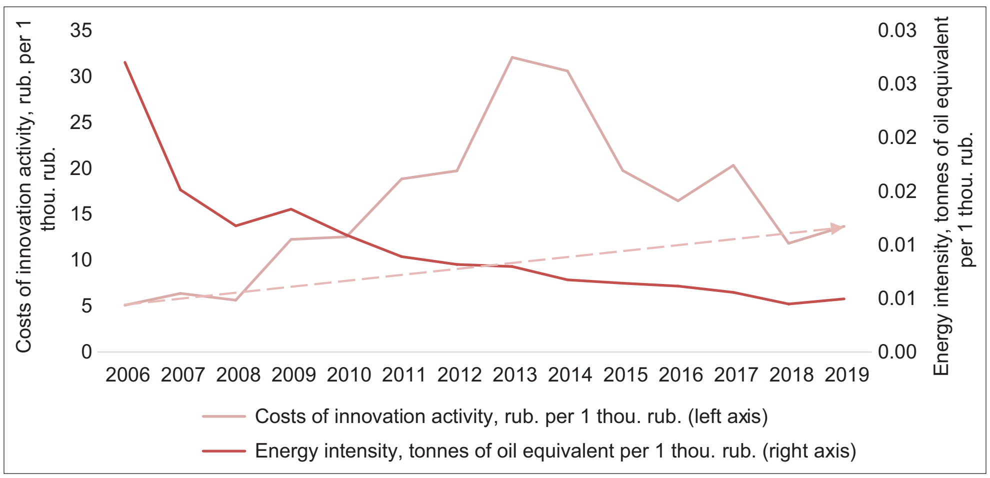


Figure 2: Dynamics of energy intensity and costs of technological innovations in the production of coke and petroleum products (built by the authors)



89%. However, the average growth rate of costs for innovative activities differs significantly: in the first case it is 100.6%, in the second - 114.7%.

The influence of innovative industrial development on energy intensity indicators was assessed by means of a scatter diagram and a correlation coefficient. On the one hand, the tightness of the relationship between the variables in both cases is noticeable - 56%; on the other hand, and what is of particular interest is the different nature of the relationship between the indicators (Figure 3). The revealed dependence (with a 95% confidence interval) makes it possible to judge the different priorities of technological transformations in two industries: in chemical industries, innovative solutions weakly affect the energy problem and are more focused on product modifications, properties and quality of new chemical products; with regard to enterprises producing coke and petroleum products, one can summarize the energy-saving development as a result of the introduction of technological innovations.

The revealed dependencies can serve as a basis for prioritizing innovative measures aimed at reducing the energy intensity of petrochemical industries.

4.2. Forecasting the Energy Intensity of Petrochemical Industries in Russia

Diagnostics of the correlation dependence made it possible to reveal the prevalence of the tightness of the relationship between energy consumption and the volume of sales of petrochemical products. Comparing the simulation results for the entire study period 2006-2019, we note a more noticeable relationship between the variables in the production of coke and petroleum products, as evidenced by the correlation coefficients r = 0.787 for this industrial production; for chemical industries - r = 0.74 (Figure 4). Thus, to a greater extent the economies of scale in terms of energy consumption are manifested in the production of petroleum products.

In addition, in each of the cases, a variant correlation analysis was carried out, as a result of which it was revealed that the strongest relationship between the indicators of energy consumption of production and the volume of sales of chemical products is observed for the period 2014-2019 - the correlation coefficient r = 0.986; energy consumption of production and sales volumes of coke and petroleum products - for 2015-2019, r = 0.967. The results of the variant analysis made it possible to determine the most qualitative regression model for each type of production.

Based on the revealed correlation, paired linear regression models were built for two types of industries. For chemical industries, an inverse relationship is characteristic due to the effect of scale - energy intensity decreases with an increase in the volume of production and sales of chemical products (Table 2). This is evidenced by the level of significance P, as well as the F- and t-tests. The relationship between the variables is strong, as evidenced by the coefficient of determination $R^2 = 0.97269$.

A similar model was built for the production of coke and petroleum products (Table 3). There is also a strong relationship between the dependent and independent variables - the coefficient of determination is 93.4%. The model should be recognized as qualitative in terms of the significance level of the P, F- and t-criteria.

Based on the regression analysis, development scenarios have been constructed that take into account fluctuations in the volume of

Table 2: Regression analysis of energy intensity of chemical industries

Parameters	Regression summary for dependent variable: Energy intensity (EI), R=0,98625; R²=0,97269; F (1,4)=142,48; P<0,00028					
	b*	Std. Err.	b	Std. Err.	t (4)	P-value
Intercept			0,026065	0,001027	25,3870	0,000014
Volume of shipped own produced goods, works performed and services rendered, trln rub. (V_{chem})	−0,986252	0,082625	−0,004354	0,000365	−11,9365	0,000282
Regression equation	$EI=0{,}02607 – 0{,}00435 * V_{chem}$					

Table 3: Regression analysis of energy intensity of coke and petroleum products production

Parameters	Regression summary for dependent variable: Energy intensity (EI), R=0,96655; R²=0,93422; F (1,3)=42,607; P<0.00731					
	b*	Std. Err.	b	Std. Err.	t (12)	P-value
Intercept			0,009407	0,000606	15,51564	0,000582
Volume of shipped own produced goods, works performed and services rendered, trln rub. (V_{petr})	-0,966551	0,148075	-0,000456	0,000070	-6,52743	0,007307
Regression equation	$EI=0{,}00941 – 0{,}00046 * V_{petr}$					

Figure 3: The relationship between energy consumption and the cost of technological modernization of petrochemical plants (built by the authors) (a) Chemical industry (b) Coke and refined petroleum products industry

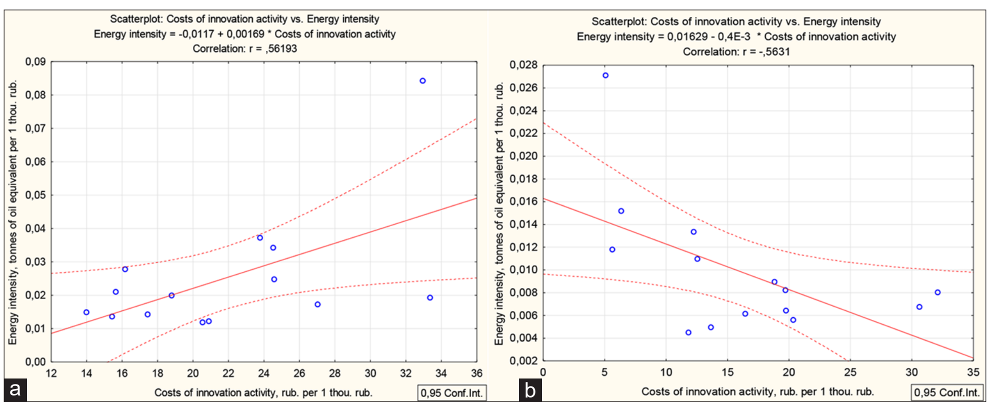


Figure 4: The relationship between energy consumption and the volume of sales of goods, works, services of petrochemical industries (built by the authors) (a) Chemical industry (b) Coke and refined petroleum products industry

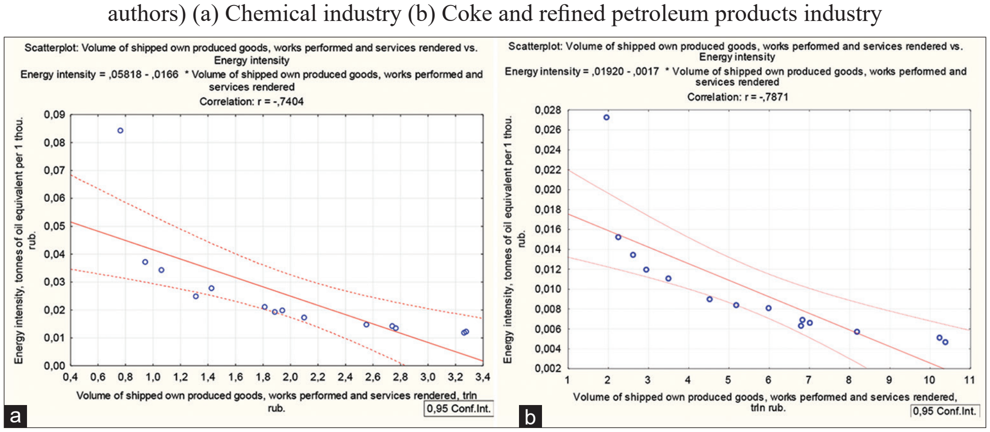


Table 4: Forecasting the energy intensity of petrochemical industries (calculated by the authors)

Year	Volume of shipped own produced goods, works performed and services rendered (bln rub.)	Energy intensity, tonnes of oil equivalent per 1 thou rub.	
		Actual value	Predicted
	Chemical industry		
2019	3,28	0,0122	0,0118
2020	3,405	-	0,0112
2021	4,5	-	0,0065
2022	4,7	-	0,0056
	Coke and refined petroleum products industry		
2019	10,25	0,0050	0,0047
2020	8,4	-	0,0056
2021	11	-	0,0044
2022	11,3	-	0,0043

The statistical data on sales volumes in 2020 were taken into account; operational statistical data on sales volumes for January-September 2021 conditionally increased by the quarterly sales volume; data for 2022 are accepted by the authors as predicted

sales of petrochemical products, including during the crisis year of 2020 (Table 4).

Thus, the energy intensity of petrochemical industries is steadily declining and has a similar tendency to decline in the future. The reason for this is not only the noted economies of scale, but also the technological modernization of production systems, the intensification of which will serve as a catalyst for the energy-saving development of industry.

5. CONCLUSION

Thus, trends in the development of petrochemical industries, which are manifested in a reduction in the energy intensity of production and a differentiated approach to technological modernization, have been investigated. The use of economic and mathematical methods made it possible to identify the features of the energy-saving development of industry in Russia and formulate the following conclusions and results:

- The regularities of the development of petrochemical industries in Russia were revealed, which consist in the fact that over the past 14 years the level of energy intensity of the noted industries has been steadily decreasing (in general, over the period it has decreased by more than 80%), which corresponds to the concept of sustainable development broadcast by the UN; the unstable dynamics of unit costs for the innovative activity of petrochemical industries was determined, which has a multidirectional nature in the case of chemical industries and the production of coke and petroleum products
- The nature of the influence of technological modernization of production on the level of energy intensity is determined, which is manifested in the difference in emphasis of innovative development: in chemical production, innovations do not contribute to solving the energy problem, in contrast to the production of coke and petroleum products
- Paired linear regression models have been built, reflecting the dependence of the energy intensity of petrochemical industries on the volume of sales of industry products, which are the basis for predicting energy intensity
- A forecast for the development of petrochemical industries in terms of increasing production volumes and sales of industrial products and further reducing energy consumption is proposed, which makes it possible to develop a set of management measures to support the energy efficient development of industry in Russia.

The results of the study can serve as a basis for improving the strategic directions of development of the petrochemical industry in Russia, taking into account the prioritization of the implementation of energy-saving innovative solutions.

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