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Article

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Modelling of Energy Efficiency Factors of Petrochemical Industry

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ABSTRACT

The relevance of the article is due to the fact that the issues of improving the energy efficiency of the petrochemical industry are constantly developing and require the development of new methodological solutions and management tools. The solution of the identified tasks will allow to reveal new directions of improvement of stability of the petrochemical complex and increase of its competitiveness. The purpose of the article is to determine the relationship between energy efficiency indicators and industrial production indicators, as well as to cluster regions in which the oil production and oil refining industry is present in order to systematize the factors of their development. The article analyses energy efficiency and energy saving systems on the example of enterprises-representatives of the petrochemical complex; the relationship between the industrial production index and energy saving indicators in the petrochemical industry has been identified; regional petrochemical complexes were clustered based on their energy intensity. The materials of the article can be used in the development of energy efficiency strategies and programs in petrochemical enterprises, which will increase their economic and production efficiency, as well as competitiveness in the context of transformation of the entire macroeconomic system to achieve its sustainability.

Keywords: Energy Efficiency, Energy Intensity of Economy, Gross Value Added, Energy-saving Technologies, Energy Consumption, Cluster Analysis
JEL Classifications: P28, C21, O14

1. INTRODUCTION

The problem of energy efficiency in the industrial complex of Russia is currently one of the most pressing, which is enshrined in the relevant policy documents and strategies for the development of Russian enterprises (Gorbunov et al., 2019). In the programs for industrial development and improvement of its competitiveness, one of the key results of its implementation was the improvement of quality, ecological safety, energy efficiency and resource saving of produced industrial products through the introduction into the production process of innovative energy-saving technologies, use of environmentally safe materials and raw materials, improving their operational properties (Cherdymova et al., 2018). Besides, discussion of trends of development of the petrochemical industry found reflection in such relevant subjects as open innovative models of management of the chemical companies, the systems of management in the field of environmental protection of the Russian chemical companies, mathematical modeling of heat exchange in a complex heat technical system, competitiveness of the industrial enterprises through realization of strategy of innovative development, process automation of oil refineries and others (Firsova et al., 2018; Mukhametshin et al., 2019).

Building the methodology and choosing the tools for organizing energy-saving production systems requires taking into account new directions of transformation of the industrial complex, one of which will be the orientation of the petrochemical industry to the use and creation of end-to-end technologies, such as big data, distributed register systems, new production technologies, industrial Internet, etc. The key objectives here are:

- Accelerating the adoption of new modern standards for the needs of the petrochemical industry;
- Development and adoption of modern standards on information technology;
- Transition to digital standards and requirements management systems.

In this regard, the problem of modelling energy efficiency factors becomes of particular importance and relevance for the petrochemical industry in the transition to the new requirements of the entire economic system, namely its digitalization and improvement of sustainability.

2. LITERATURE REVIEW

The issues of methodology and instruments of organization of energy-saving production in petrochemical industry in foreign and domestic scientific literature occupy one of the central provisions in the field of industrial production. The organization of systems of planning and control of production processes of petrochemical industries focuses on solving the problem of using energy-saving technologies to optimize the entire production chain of the petrochemical enterprise and related industries. Among the most studied issues in the foreign literature in this direction are the works of the following authors: Tozzi and Jo (2017) have conducted a comparative analysis of renewable energy modeling tools based on the construction of a model of performance simulation at the petrochemical enterprise and system optimization; Nikolaidis and Poulikkas (2017) is a comparative review of hydrogen production processes as intermediate production in the petrochemical industry; Cucchiella et al. (2017) - comparison of environmental and energy performance of European countries based on the sustainability index; Akhavein and Porkar (2017) focused on the research objectives of petrochemical manufacturing using a comprehensive system to test the reliability of power generation and transmission in petrochemicals; Ram et al. (2017) focused on reducing energy consumption in the petrochemical complex Dellano-Paz et al. (2015) offered a technique of assessment of use of renewables in petrochemistry on the basis of ecological and social indicators which approbation took place within the "European Low-carbon Mix for 2030" program; Sovacool (2015) emphasized the issues of "pollution markets" of petrochemical complex, having developed recommendations for energy consumption planning in this industry; Nasiri et al. (2015) studied innovative aspects of energy consumption in petrochemicals; Degtyarev et al. (2014) offered scientific support of program power and resource saving; Kolotyrin et al. (2019) reviewed the use of resource-saving technologies in related petrochemical industries; Klochko and Brizhak (2019) Analyze virtual technologies in the petrochemical complex. However, the above-mentioned works do not fully reflect the key principles of resource saving in chemical-technological systems, which can be considered as the main ones for petrochemical enterprises. Resource efficiency issues, including through the use of innovative technologies in the industrial complex, are also presented in the works of authors: Shinkevich et al. (2017); Shinkevich et al. (2018); Shinkevich et al. (2019); Ahmed et al. (2019); Podymov et al. (2019).

At the same time, with an extensive theoretical and methodological array of data and practical solutions, there is still no unified methodology for assessing energy efficiency factors of the petrochemical industry, which would combine the latest achievements of modern science of technical systems management, production organization and take into account the peculiarities of prerequisites for formation of demanded technologies and solutions for this industry.

3. DESCRIPTION OF THE STATISTICAL BASIS OF THE STUDY

In the Russian industrial complex, even the rapid development of scientific and technological progress has little influence on the change of the technological order of the petrochemical industry. For example, the share of production of progressive materials is 2-3 times lower than in industrialized countries. The share of products produced using the first generation technologies is more than half a thousand in the total volume of production which causes an increase in production costs and increases its environmental burden, calls into question the technological safety of production processes, thus affecting the level of competitiveness of the domestic petrochemical industry (Ram et al., 2017).

Average energy and material consumption for the main chemical products is 1.5-2 times higher than in the leading countries, consumption of technological and defense water - by 20-25%, the degree of wear of fixed assets is 49.6%.

Energy consumption in the petrochemical complex is one of the highest in the Russian industry. Thus, 18.9 million tons of natural fuel, 19.6 million tons of boiler-furnace fuel and 47.9 million tons of electricity were consumed from the total final consumption in mining organizations according to the energy balance data for 2017; 4 million tons of natural fuel, 6.5 million tons of boiler-furnace fuel and 14.5 million tons of electricity, respectively, in chemical production organizations; In the production of coke and petroleum products - 3.8 million tons of natural fuel, 25.1 million tons of boiler-furnace fuel and 7.9 million tons of electricity.

Programs and projects to modernize the petrochemical complex of Russia have a positive effect, which is reflected in the decline of such indicator as energy intensity of gross domestic product (GDP) per petrochemical enterprise, the value of which decreased from 129.62 kg of conventional fuel by 10 thousand rubles in 2012 to 104.72 kg of conventional fuel per 10 thousand rubles in 2017. The most energy intensive are petrochemical enterprises of Kemerovo region (452.01 kg of conventional fuel per 10 thousand rubles), Vologda region (408.38), Lipetsk region (383.952), Republic of Hakassia (373.24) and Tyva (316.41). Positive dynamics is noted in consumption of fuel and energy resources per one employed in the petrochemical complex, which decreased from 29 tons of conventional fuel in 2012 to 27.1 tons in 2017 of conventional fuel.

The share of renewable energy resources is positive. In the total volume of energy resources, which increased from 15.3% in 2012 to 17% in 2017. The leader in this indicator is petrochemical enterprises of the regions of the Siberian Federal District with a value of 45.8% and with a maximum increase over a 6-year period of 5.6% points (Table 1) (Rosstat, 2019).

At the same time, among the negative points should be noted the growth of electric labor ratio in the petrochemical industry: according to the results of 2017 the value of this indicator amounted to 60.741 kWh, having increased in comparison with 2012 by 7.839 kWh, or 14.8%. As a whole, the industrial production in 2017 was 73067 kWh (Table 2) (Rosstat, 2019).

The share of electricity consumption for technological needs in the total volume of electricity consumption of industrial organizations over the last 5 years shows stability without significant fluctuations of the indicator: on average for 2013-2017 the value of this indicator for petrochemical enterprises was 41.2%, in general for industry - 25.2%.

In the structure of expenditures of petrochemical enterprises on payment of energy resources the largest share is occupied by electricity - 38,2%, gas - 26.4%, coal - 10.6%, oil products – 7.9%, other types of fuels - 7.3%. Distribution of actual consumption of electricity, heat and fuel per unit of certain types of produced products in the petrochemical complex according to the results of 2017 showed, That the greatest expenditures are in the production of synthetic rubbers, plastics, acyclic hydrocarbons, paint and varnish materials, oil production (Rosstat, 2019).

4. METHODS AND MODELS

The main method for studying the level of energy conservation at the enterprises of the petrochemical complex is the *k*-means method, the analysis tool is the Statistica software product.

The k-means method is a cluster analysis method, the purpose of which is to divide m observations (from space R^n) into k clusters and each observation refers to the cluster whose center (centroid) it is closest.

As a measure of proximity, the Euclidean distance is used:

$$\rho(x,y) = \|x-y\| = \sqrt{\sum_{p=1}^{n}(x_p - y_p)^2}\text{, where } x, y, \in R^n$$

For example, there are a number of observations $\left(x^{(1)}, x^{(2)}, \ldots, x^{(m)}\right) x^{(j)} \in R^n$.

The method of *k*-means divides m of observations into k of groups (or clusters) ($k \le m$) to minimize a total square deviation of points of clusters from centroid of these clusters:

$$\min\left[\sum_{i=1}^{k}\sum_{x^{(j)}\in S_i}\left\|x^{(j)} - \mu i\right\|^2\right]\text{, where } x^{(j)} \in R^n, \mu_i \in R^n,$$

μ_i - Is the centroid for the cluster.

Thus, if the measure of proximity to the centroid is determined, the division of objects into clusters is reduced to determining the centroids of these clusters. The number of clusters k is predetermined by the researcher.

Consider the original set of k - means (centroids) $\mu_1,\ldots, \mu_k$ in clusters $S_1, S_2,\ldots, S_k$. In the first step, cluster centroids are selected accidentally or according to a certain rule (for example, select centroids that maximize the initial distances between clusters).

We refer to those clusters whose average (centroid) is closest to them. Each observation belongs to only one cluster, even if it can be attributed to two or more clusters.

The centroid of each i^{th} cluster is then re-distinguished by the following rule:

$$\mu_i = \frac{1}{S_i}\sum_{x^{(j)}\in S_i} x^{(j)}$$

Thus, the k-means algorithm consists in the re-identification at each step of the centroid for each cluster obtained in the previous step.

The algorithm stops when the values μ_i do not change: $\mu_i \mu_i^{step\,t} = \mu_i^{step\,t+1}$.

Table 1: Share of renewable energy resources in total petrochemical energy resources (percentage)

Petrochemical industry representative enterprises	2012	2013	2014	2015	2016	2017	Growth (decrease)
Russian Federation (average value)	15.3	17.1	16.4	15.8	17.0	17.0	1.7
Slavneft-Janos, Lukoil-Volganeft-product, Oskolnefte-snab (Central Federal District)	0.8	0.8	0.4	0,3	0.6	0.9	0.1
Rosenergoexport, Tetoil, Lukoil-Komi (Northwestern Federal District)	11.9	10.9	10.2	11.2	11.1	11.9	0.0
Neftetrade, Kuban Oil and Gas Company, Afip Refinery (Federal District)	22.5	23.0	20.4	18.7	18.3	20.9	−1.7
Svyaztransneft, Rosneft - Dagneft, Neftekhimproject (North Caucasian Federal District)	27.1	35.4	26.3	26.3	30.2	25.4	−1.7
Kazanorgsintez, Tatneft, Bashneft (Volga Federal District)	13.8	14.9	14.4	15.1	15.2	17.7	3.9
Rospan International, West Siberian Petroleum Complex, Chernogornefteotdacha (Ural Federal District)	0.01	0.01	0.01	0.02	0.01	0.02	0.0
Tomsk Petrochemical Plant, Khimprom, Siberian Chemical Plant (Siberian Federal District)	40.3	46.7	46.2	43.7	47.4	45.8	5.6
Petrosakh, Sakhneftegas, Yakutgazprom (Far Eastern Federal District)	34.8	37.7	35.5	30.5	35.9	33.4	−1.4

Important: Incorrect selection of the initial number of clusters k can lead to incorrect results. That is why, when using the k-means method, it is important at first to check the appropriate number of clusters for a given dataset.

5. RESULTS AND DISCUSSIONS

The analysis revealed that none of the energy efficiency indicators in the Russian petrochemical industry correlates with the index of industrial production (IPP) of the petrochemical sector, which makes it possible to speak about the different directions of resource and energy efficiency policy with the change in the rate of output of petrochemical products (Table 3).

To estimate the level of energy saving at the petrochemical complex enterprises (on the example of the regional petrochemical complex), we will use the cluster analysis procedure, the *k*-means method. As the analyzed indicators will be used data on the energy intensity of gross regional product (GRP) and electric labor ratio in the regions of the Volga Federal District (PFD).

The results of the cluster analysis showed that the distribution of petrochemical representative enterprises in the regional section of the PFD according to the analyzed indicators is characterized by synchronous changes. In total 3 groups of petrochemical enterprises were allocated. The feasibility of dividing the sample into 3 clusters is confirmed by the obtained results of the dispersion analysis, which showed the statistical significance of the analyzed variables: energy intensity of GVA of petrochemical enterprises is statistically significant at the 10% level, electric labor ratio - at the 5% level, as evidenced by their P-values (Table 4).

Table 2: Electric labor ratio of employees of petrochemical enterprises (kWh)

Year	Total in industrial production	Petrochemical complex
2012	67448	52902
2013	69249	53680
2014	68498	54153
2015	69697	55606
2016	71335	57002
2017	73067	60741

The group of petrochemical enterprises with high-energy intensity of GVA and electric labor ratio includes 4 enterprises with an average value of 201.12 kg of conventional fuel/per 10 thousand rubles and 61180 kWh, respectively: Tatneft, Bashneft, Lukoil-Perm and Orenburgneft. The group of petrochemical enterprises with average energy intensity of GVA and electric labor ratio also included 4 petrochemical enterprises with average values of 173.37 kg of conventional fuel/per 10 thousand rubles and 38414 kWh: Kirovsk Tire Plant, Orgsintez, Kuibeshevazot and Saratov Oil Refinery. The largest group of petrochemical enterprises with energy intensity of GVA and electric labor ratio, in which the average values of the analyzed indicators were 150.12 kg of conventional fuel/per 10 thousand rubles and 18340 kWh, respectively: Mari Oil Refinery, Saransk Rubber Technical Products Plant, Udmurtnefteproduct, Promneft, Agronefteproduct (Table 5).

At the same time, it should be noted that the lowest variability of energy intensity of GVA in petrochemical enterprises was observed in the middle cluster, where the value of mean square deviation was lowest - 6.8, in the low cluster the mean square deviation of energy intensity of GVA of petrochemical enterprises was 15.5. According to the electric labor ratio, the standard deviation of the middle and low clusters was approximately the same - 4803 versus 4663.

Using the calculated values of the coefficient of variation as a ratio of the standard deviation to the average value for each selected cluster, groups of petrochemical enterprises were determined according to the level of stability of energy saving processes (Table 6).

The cluster of petrochemical enterprises with a developed petrochemical industry, which is characterized by high energy intensity of GVA and electric labor ratio from the point of view of stability of the level of resource saving is the most vulnerable

Table 3: Relationship of IPP and energy saving indicators in petrochemical complex

Indicator	IPP, %	Energy intensity of gross value added (GVA) of petrochemical enterprises, MJ/USD USA	Energy consumption, kg of oil equivalent per 1 petrochemical plant	Renewable energy consumption in petrochemical plants,% of total final energy consumption
IPP, %	1			
Energy intensity of GVA of petrochemical enterprises, MJ/USD USA	0.13	1		
Energy consumption, kg of oil equivalent per 1 petrochemical plant	−0.27	−0.86	1	
Renewable energy consumption in petrochemical plants, % of total final energy consumption	−0.07	0.27	−0.16	1

Table 4: Dispersive analysis

Indicator	Between - SS	df	Within - SS	df	F	Signif. - P
Energy intensity of GVA of petrochemical enterprises, conventional fuel/per 10 thousand rubles	6.265558E+03	2	10454	11	3.29639	0.075565
Electric labor ratio, kWh	4.429424E+09	2	432360800	11	56.34607	0.000002

Table 5: Descriptive statistics of cluster analysis

Indicator	Average value	Mean square deviation	Dispersion
	High (Tatneft, Bashneft, Lukoil-Perm and Orenburgneft)		
Power consumption of GVA, conventional fuel/per 10 thousand rubles	201.12	55.1	3036
Electric labor ratio, kWh	61180	9208	84802070
	Middle (Kirovsk Tire Plant, Orgsintez, Kuibeshevazot, Saratov Oil Refinery)		
Power consumption of GVA, conventional fuel/per 10 thousand rubles	173.37	6.8	47
Electric labor ratio, kWh	38414	4803	23074920
	Low (Mari oil refinery, Saransk rubber technical products plant, Udmurtnefteproduct, Promneft, Agronefteproduct, Ulyanovskneft)		
Power consumption of GVA, conventional fuel/per 10 thousand rubles	150.12	15.5	241
Electric labor ratio, kWh	18340	4663	21745870

Table 6: Classification of petrochemical enterprises of PFD regions by the level of stability of energy saving processes

Indicator	Cluster and its member regions	Coefficient of a variation, %	Stability level
Power consumption of GVA, conventional fuel/per 10 thousand rubles	High (Tatneft, Bashneft, Lukoil-Perm and Orenburgneft)	27.4	Low, factor of stability achievement - due to electric labor ratio
Electric labor ratio, kWh		15.1	
Power consumption of GVA, conventional fuel/per 10 thousand rubles	Middle (Kirovsk Tire Plant, Orgsintez, Kuibeshevazot, Saratov Oil Refinery)	3.9	High
Electric labor ratio, kWh		12.5	
Power consumption of GVA, conventional fuel/per 10 thousand rubles	Low (Mari oil refinery, Saransk rubber technical products plant, Udmurtnefteproduct, Promneft, Agronefteproduct, Ulyanovskneft)	10.3	Medium, stability factor - due to energy intensity of GVA
Electric labor ratio, kWh		25.4	

in view of high volatility of these indicators, at the same time due to less strong spread within the index of electric labor ratio, this factor can act as a driver of energy efficiency policy. In a cluster of petrochemical enterprises with a low level of development of the petrochemical industry which is characterized by low energy intensity of GVA and electric labor ratio, on the contrary, the stability of energy saving is noted as "medium," with the driver of energy efficiency policy on such indicator as "energy intensity of GVA of petrochemical enterprises." Petrochemical enterprises with medium level of development of petrochemical industry are characterized by the most stable position in realization of directions of energy efficiency.

6. CONCLUSION

Thus, the analysis of energy saving at petrochemical enterprises makes it possible to draw the following conclusions:

- Modernization of petrochemical complex in the direction of implementation of energy saving programs has a positive effect, which has led to reduction of energy intensity of gross value added of petrochemical enterprises, from 129.62 kg of conventional fuel by 10 thousand rubles in 2012-104.72 kg of conventional fuel by 10 thousand rubles in 2017;
- Positive dynamics is observed in consumption of fuel and energy resources per one employed in the petrochemical complex, which decreased from 29 tons of conventional fuel in 2012-27.1 tons in 2017 of conventional fuel;
- A positive trend is the share of energy resources produced using renewable energy sources at petrochemical enterprises in the total volume of energy resources, which increased from 15.3% in 2012 to 17% in 2017;
- On the contrary, the electric labor ratio in the petrochemical industry increased by almost 155 in 2017 compared to 2012, amounting to 60741 kWh;
- The main consumers of resources, including energy, continue to be "heavy" chemistry enterprises engaged in the production of synthetic rubbers, plastics, acyclic hydrocarbons, paint and paint materials, oil production;
- During the industrial and financial crisis of 2007-2012, the "winding down" of the petrochemical industry of Russia contributed to the reduction of energy intensity of the economy as a whole, but among the world leaders of petrochemical production the energy intensity of the Russian petrochemical industry remains the highest;
- In terms of renewable electricity output in the petrochemical industry, the situation of Russia (15.9%) is similar to that of France (15.9%), Japan (16%) and exceeds that of the United States (13.2%); Among the negative factors should be mentioned the decrease in this indicator in the petrochemical industry of Russia compared to 2000 by 2.9% points, for other industrial countries under consideration there was a positive trend;
- Energy saving indicators in the Russian petrochemical industry do not correlate with the index of industrial production of the petrochemical sector, which makes it possible to speak of different directions of energy efficiency policy with change in the rate of output of petrochemical products;
- In the petrochemical industry there is a synchronous change in the energy intensity of gross value added of petrochemical

enterprises and electric labor ratio, but the most stable trend is demonstrated by petrochemical enterprises with a medium level of development of petrochemical production, respectively, programs and projects of energy saving at petrochemical enterprises require deeper analysis and primary response at this type of petrochemical enterprises.

The materials of the article can be used in the development of energy efficiency strategies and programs in petrochemical enterprises, which will increase their economic, and production efficiency, as well as competitiveness in the context of transformation of the entire macroeconomic system to achieve its sustainability.

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