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**Article**

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# State Priorities in the Petrochemistry of Russia: Sustainable Development, "Green" Industry and Energy Efficiency

**Marina V. Shinkevich[1]*, Irina G. Ershova[2], Izida I. Ishmuradova[3], Valeriy I. Prasolov[4], Alexey I. Prokopyev[5], Yana A. Cherezova[6]**

[1]Department of Logistics and Management, Kazan National Research Technological University, Kazan, Russian Federation, [2]Department of Finance and Credit, Southwest State University (SWSU), Kursk, Russian Federation, [3]Department of Business Informatics and Mathematical Methods in Economics, Kazan (Volga region) Federal University, Kazan, Russian Federation, [4]Department of Economic Security and Risk Management, Financial University under the Government of the Russian Federation, Moscow, Russian Federation, [5]Department of State and Legal Disciplines, Plekhanov Russian University of Economics, Moscow, Russian Federation, [6]Department of Economics and Management, I.M. Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russian Federation. *Email: leotau@mail.ru

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**ABSTRACT**

This research aims at diagnosing such priority areas for the development of petrochemicals in Russia as sustainable development and energy efficiency, at identifying trends and forecasting the development of the industry, taking into account the greening of the industry. Achieving the goal is based on the use of methods such as graphical, comparative, economic and mathematical (neural network modeling, correlation regression analysis), and prognostic. The article contains an assessment of the achievement of the sustainable development goals focused on energy saving and environmental protection; forecasting the level of greenhouse gas emissions in Russia based on the construction of a neural network and a regression model; comparative analysis of the rates of transition to sustainable development of chemical production and production of coke and petroleum products in the Russian economy. The scientific results of the research are a neural network model trained on the indicators of sustainable and energy efficient development of the Russian economy, on the basis of which the relationship between the level of greenhouse gas emissions, the energy intensity of GDP and the share of electricity from renewable energy sources is formalized; a predictive model that made it possible to calculate future values of greenhouse gas emissions depending on the target values of predictive variables; features of the greening of petrochemical industries in Russia.

**Keywords:** Petrochemical Industry, State Priorities, Sustainable Development, Green Industry, Energy Efficiency, Russia
**JEL Classifications:** O14, D24, C41

## 1. INTRODUCTION

The global economic problem today is environmental pollution as a result of the activities of industrial enterprises. As a result, society is negatively affected, in connection with which the priorities of state regulation of economic development are shifted towards environmental protection, stimulating the development of technological solutions that can prevent the destructive impact of industry. As a result, the sectoral policy of macroeconomic systems today is focused on increasing production rates with the maximum possible preservation of natural resources and minimal destruction of the environment, at ensuring energy efficiency, sustainability and reliability of industrial production, at creating working conditions under which a product of adequate quality will be obtained.

A high level of polluting emissions (into water bodies and into the atmosphere) and consumption of energy resources in Russia is typical for enterprises of the petrochemical industry (Federal State Statistic Service, 2020). In this regard, it is relevant to study the trends in the development of petrochemistry in Russia and the priority directions of state regulation of its effective development. The United Nations Sustainable Development Goals are the key international strategic initiatives for the protection of the environment within the petrochemical industry. (United Nations, 2020), the green industry concept developed by UNIDO (United Nations Industrial Development Organization, 2020), as well as the creation of an international organization “Sustainable Energy for All,” whose activities are focused on the implementation of measures to achieve Goal 7 in the field of sustainable development and increase the energy efficiency of industry (Sustainable Energy for All, 2020).

The up-to-date direction of industrial development is the implementation of “green” concepts – “green industry,” “green energy,” “green economy.” Green industry refers to a strategy of resource efficient, cleaner production, prevention of the destructive impact of chemical emissions into the atmosphere and hydrosphere, as well as staffing the process of greening industries. These initiatives are broadcast in the Russian economy in the form of provisions of federal strategies, plans and development programs that regulate and stimulate the introduction of breakthrough technologies. “Green Energy” is aimed at the transition to renewable energy sources - wind, solar, biofuels, etc. “Green Economy” is focused on the qualitative development of socio-economic systems with a reduction in negative environmental burden.

State support for industrial modernization is especially important. The priority areas of financing the technological development of production are rational use of natural resources and energy efficiency, for the financing of which the state budget (of all levels) in 2019 allocated 24.5 and 73.5 billion rubles respectively. State financial support for energy-saving development is increasing annually: in 2015, funding from budget funds amounted to 57.4 billion rubles (Federal State Statistic Service, 2020).

Thus, the covered issues actualizes the importance of state participation in the development of the petrochemical industry and predetermines the importance of studying the Russian practice of implementing instruments for state regulation of industry in the context of increased interest in environmental protection.

## 2. LITERATURE REVIEW

The close attention of scientists today is focused on practically significant issues affecting the problems of implementing the principles of sustainable development in industry. The scientific literature presents a wide array of works, the attention of which is drawn to the absolute importance of building integrated supply chains in order to ensure sustainable development (Shamsuddoha, 2015), development of methods for assessing the reliability of industrial production, taking into account the principles of sustainable development (Lubnina et al., 2016), the objective need to understand the potential for sustainable development in order to increase the competitiveness of industrial enterprises (Chen, 2017), macroeconomic factors that determine the sustainable development of manufacturing industries (Pieloch-Babiarz et al., 2020), pollution of the hydrosphere by industrial enterprises, regional features of managing the sustainable development of the Russian economy in the context of rational water use (Galimulina et al., 2020).

A particularly important area of knowledge in the context of sustainable development is formed around the formation of directions and modeling of energy conservation and energy efficiency. The scientific literature covers the study of such problems and issues as the construction of predictive models (in particular, triple exponential smoothing) of energy consumption on the example of China (Zhou and Chen, 2019), the role of political and economic factors in the regulation of the energy complex (Wu, 2019), modeling equations describing the impact of environmental innovation, entrepreneurial orientation and entrepreneurial self-efficacy on energy efficiency (Ahmed et al., 2020), methodological aspects of energy efficiency in manufacturing industries, its dependence on external factors (Tiep et al., 2021), a systematic approach to the management of emissions, waste, waste disposal, unused energy resources (Glinushkin et al., 2021), identification of reserves for minimizing energy losses in the chemical industry, in particular, using methods of neural network modeling (Shinkevich et al., 2021) etc.

The particular interest for science are questions of “green industry,” the preconditions of its development, the specifics of implementation in different countries. So the study of this issue was reflected in the form of cluster analysis regarding greenhouse gas emissions and energy consumption. (Mao et al., 2019); studying the experience of Asian countries in the development of “green energy,” nuclear energy (Panina et al., 2020); in conjunction with the socio-economic characteristics of the industry, in particular the employment and salaries of employees (Hall et al., 2020); from the standpoint of the country specifics of state regulation and stimulation of the production of renewable energy sources (Daryono et al., 2019; Gibbs, 2021) etc.

At the same time, the variety of scientific approaches to sustainable development and energy efficiency management weakly affects unbalanced development in the context of industrial sectors, which, in our opinion, is an important area of research in order to form a set of recommendations for the strategic vector of the activities of government bodies.

## 3. DESCRIPTION OF DATA

State regulation of sustainable development is reduced not only to the legislative function in the field of energy conservation regulation (Federal Law “On Energy Saving and on Increasing Energy Efficiency and on Amendments to Certain Legislative Acts of the Russian Federation”), but also to strategic planning, the development of a methodology for assessing the achievement of the Sustainable Development Goals in Russia, stimulating industry towards environmentally friendly production, financial support for priority areas of technological development (Figure 1).

The Federal State Statistics Service in Russia has formed a methodological basis for assessing the achievement of the Sustainable Development Goals in Russia. Taking into account the issues under study, indicators reflecting the achievement of Goal 7 "Affordable and clean energy" are of interest (Figure 2). With an increase in the scale of industrial production, the energy intensity of GDP also increases. The dynamics of the indicator is not unambiguous, but the polynomial trend line with a reliability of 57% demonstrates the growth of the indicator in the future. In general, over the 7 years presented, the indicator increased from 129.7 to 131.6 kg of standard fuel by 10 thousand rubles GDP. A less stable trend can be traced in the indicator of the share of electricity produced using renewable energy sources, where the quality of the trend line approximation was <50%.

From the point of view of state priorities for industrial development, it is important not only to regulate energy efficiency, but also to ensure favorable conditions (including investment and innovation) for the introduction of advanced technologies that can form a "green industry" in the Russian economy.

The two graphs (Figure 3) show an inverse relationship between the indicators. In the first case (Figure 3a), the growth in the energy intensity of GDP is accompanied by a reduction in the level of greenhouse gas emissions. Such a connection may be due to the diffusion of innovative technologies among Russian enterprises, automation and digitalization of industrial production, which, on the one hand, contribute to an increase in output, on the other hand, the development of the principles of a circular

**Figure 1:** Priority directions of state regulation of sustainable industrial development in Russia (compiled by the authors)

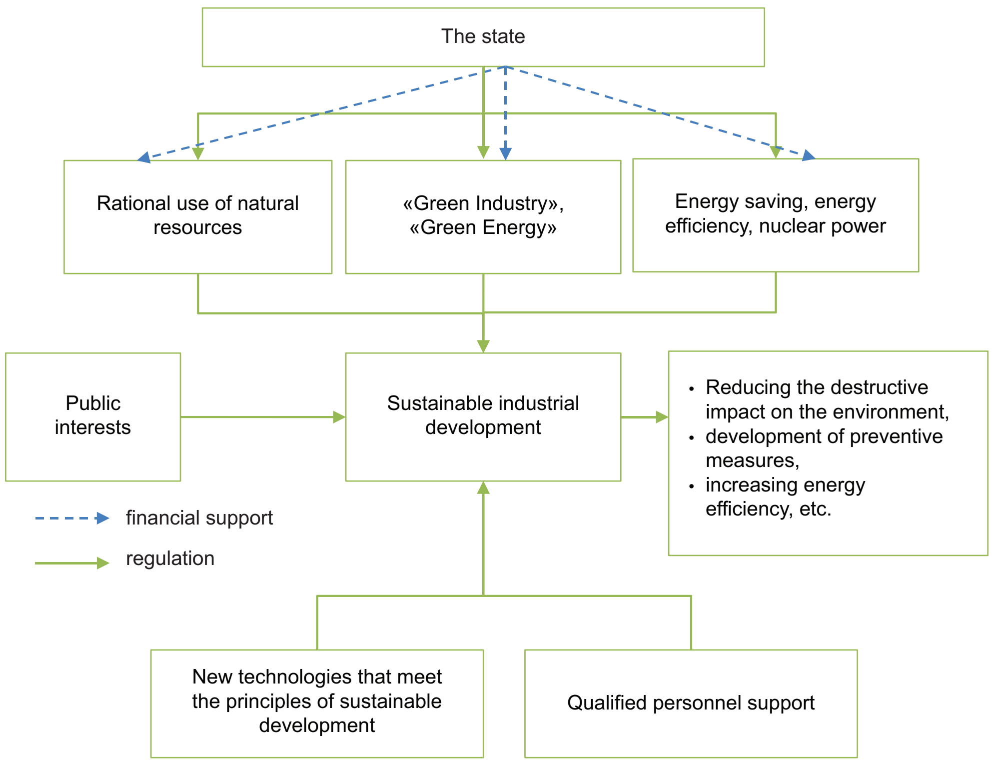
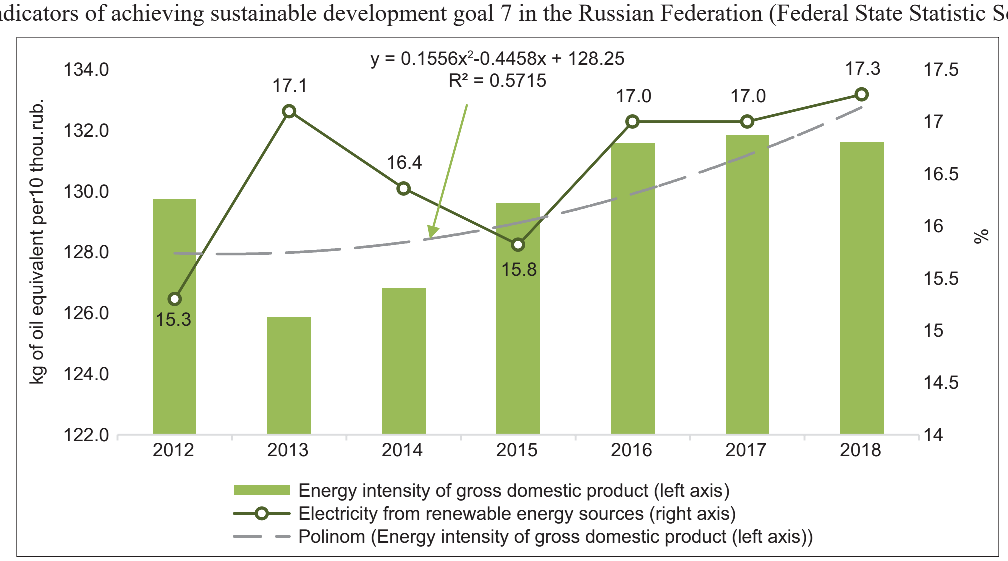



**Figure 2:** Indicators of achieving sustainable development goal 7 in the Russian Federation (Federal State Statistic Service, 2020)



economy based on waste-free production. In the second case (Figure 3b), increased use of electricity from renewable energy sources also helps to reduce the negative impact of the economy on the environment.

With regard to Russian petrochemical enterprises, it is necessary to note a decrease in the energy intensity of the goods and services sold (Figure 4). Energy consumption prevails in chemical industries, which decreased over the allocated period by 67.25% (from 0.037 to 0.012 tons of fuel equivalent per 1000 rubles). A similar growth rate was recorded for the production of coke and petroleum products, the reduction was 67.3% (from 0.015 to 0.005 tons of fuel equivalent per 1000 rubles). According to the polynomial trend lines, the tendency to reduce the consumption of energy resources by enterprises of the petrochemical industry in Russia extends to the coming periods, which corresponds to the principles of sustainable development and "green" industry.

The analytical study revealed the nature of the relationship between the energy intensity of petrochemical enterprises and the intensity of pollution, calculated relative to the volume of shipped goods and services (Figure 5). The time series covers the period from 2007 to 2019.

Comparative analysis of the dependencies shown in Figures 2 and 4, allows us to assert that, in general, the Russian economy is characterized by an increase in the energy intensity of GDP (global trends in the macroeconomic system), but within the framework of petrochemical industries, which are a large consumer of energy resources and have a high negative impact on the environment (sectoral trends in the macroeconomic system), there is a high correlation between the above indicators.

Thus, on the one hand, it is necessary to emphasize the positive effect of the development of the Russian economy along the vector of sustainable development and the transformation of industrial production into energy efficient ones; on the other hand, industry specificity gives an indication of the fact that energy efficiency measures will contribute to improving the environmental situation in the country. In this regard, an important aspect is the development of a methodology for predicting indicators of sustainable development and energy-saving industrial development, as well as identifying the specifics

**Figure 3:** Correlation between indicators of achievement of goals 7 and 9 of sustainable development in the Russian Federation (constructed by the authors according to the Federal State Statistic Service [2020]) (a) Energy intensity of gross domestic product and Greenhouse gas emissions per unit of gross domestic product (b) Electricity from renewable energy sources and Greenhouse gas emissions per unit of gross domestic product

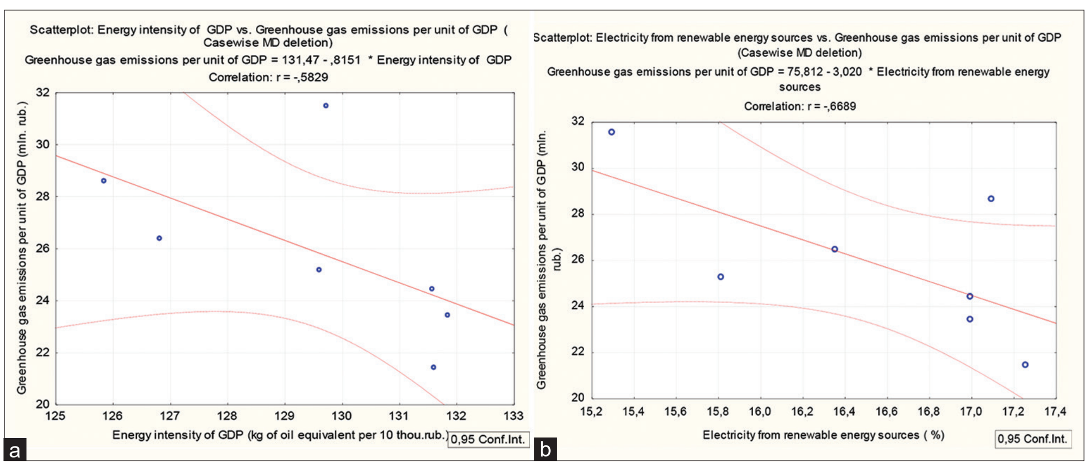



**Figure 4:** Consumption of energy resources by petrochemical enterprises in Russia (calculated by the authors according to the Federal State Statistic Service [2020])

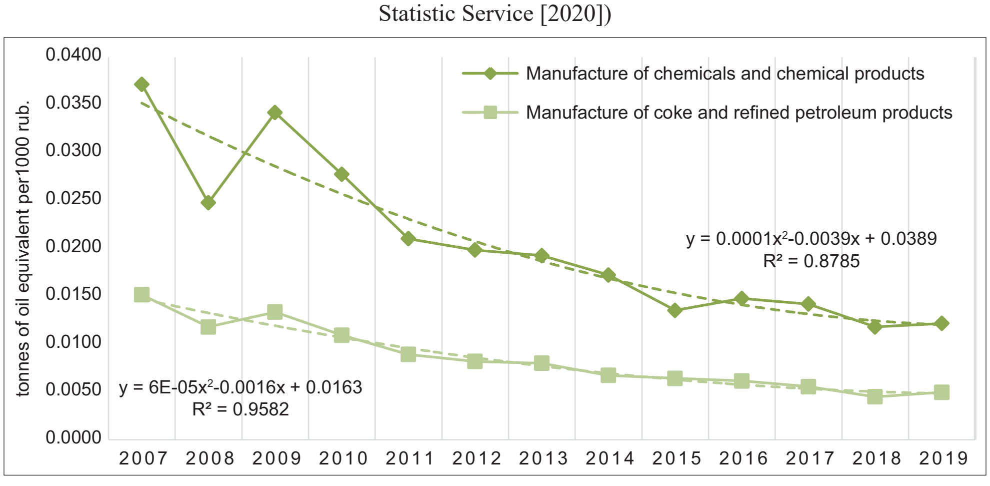
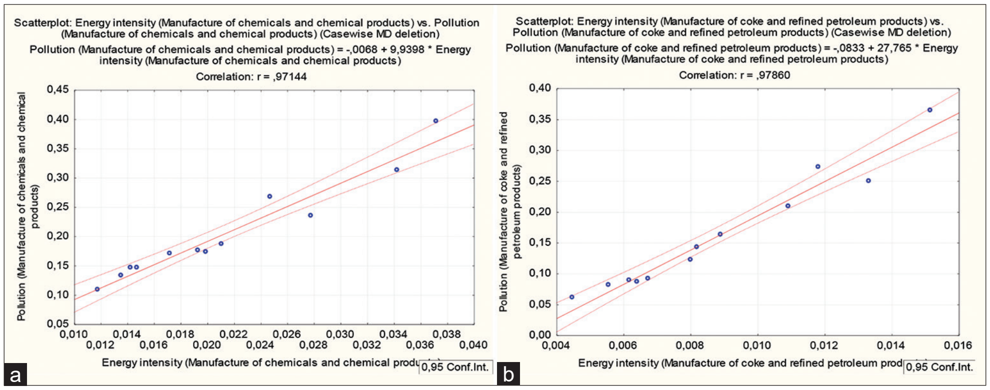


**Figure 5:** Correlation between energy consumption and environmental pollution by petrochemical enterprises (built by the authors based on data from the Federal State Statistic Service [2020]) (a) Manufacture of chemicals and chemical products (b) Manufacture of coke and refined petroleum products




of sustainable development of the petrochemical complex industries.

## 4. METHODS AND MODELS

The study was carried out in two main stages and reduced to studying the trends of sustainable development and energy efficiency in Russia on:
1. Macroeconomic level
2. Industry level (in relation to petrochemical industries).

The main methods for studying sustainable development and energy efficiency of the Russian economy and petrochemical industries were:
1. Neural network modeling based on network training based on continuous data characterizing the energy intensity of GDP, the level of electricity use from renewable energy sources and the volume of greenhouse gas emissions per unit of GDP
2. Forecasting based on the construction of a neural network, and allowing to assess future trends in sustainable development of the Russian economy, to identify the nature of modernization of the Russian economy in the context of environmental protection
3. Comparative analysis of energy-saving and sustainable development of chemical production and production of coke and petroleum products in Russia, which makes it possible to identify the distinctive characteristics of their functioning.

The construction of a neural network is based on the formation of the function of the dependent variable Y from the predictor variables $x_i$. The application of the sigmoidal function of activation of the hidden and output layers is carried out in accordance with the formula:

$$Y = \text{Sigmoid}((H_1 * w_{H1}) + w_2), \quad (1)$$

where Y – Greenhouse gas emissions per unit of GDP, tonnes per mln. rub.;
$w_{H1}$ – hidden layer neuron weight;
$w_2$ – the weight of the bias neuron on the hidden layer;
$H_1$ is neuron of the hidden layer, which is determined by the formula:

$$H_1 = \text{Sigmoid}((x_1 * w_{x1}) + (x_2 * w_{x2}) + w_1), \quad (2)$$

where $x_1$ – Energy intensity of gross domestic product, kg of oil equivalent per 10 thou. rub.;
$x_2$ – Electricity from renewable energy sources (%);
$w_{x1}$, $w_{x2}$ – the weight of the input variables $x_1$ and $x_2$, respectively;
$w_1$ – the weight of the bias neuron on the input layer.
The sigmoidal function is:

$$f(x) = 1/(1+e^{-x}). \quad (3)$$

Evaluation of the quality of the neural network is carried out according to the error values of the sum of squares of the training and test samples.

The initial data for the study are presented in Table 1.

The next stage of the study is to identify the features of sustainable development and energy efficient development of petrochemical industries. Diagnostics of the industry is based on the study of correlations between variables in the context of two large branches of Russian industry - chemical production and production of coke and petroleum products. The empirical base is presented by calculated authors based on Rosstat data (Federal State Statistic Service, 2020) by energy efficiency indicators:
$x_{1i}$ – Energy intensity (tonnes of oil equivalent per 1 thou. rub.);
$x_{2i}$ – Pollution as the ratio of the volume of emissions into the atmosphere of pollutants to the volume of shipped goods and services in the i-th industry (tonnes per 1 mln. rub.);
$x_{3i}$ – Industrial and municipal wastes as the ratio of the volume of waste to the volume of shipped goods and services in the i-th industry (tonnes per 1 thou. rub.);
i – petrochemical industry (Manufacture of chemicals and chemical products или Manufacture of coke and refined petroleum products).

In turn, the listed indicators for assessing the energy efficiency of petrochemical industries are calculated using the formulas:

$$x_{1i} = ER_i/Q_i \quad (4)$$

where $ER_i$ – the volume of energy resources consumed in the i-th industry is taken into account the volumes of consumption of fossil fuel, fuel products, electricity and heat (mln. tonnes of oil equivalent);

$Q_i$ – volume of shipped goods, works and services in the i-th industry (bln. rub.);

$$x_{2i} = P_i/Q_i, \quad (5)$$

where $P_i$ – the volume of pollutants emitted into the atmosphere in the i-th industry (thou. tonnes);

$$x_{3i} = W_i/Q_i, \quad (6)$$

where $W_i$ – the volume of production and consumption waste in the i-th industry (mln. tonnes).

## 5. RESULTS AND DISCUSSIONS

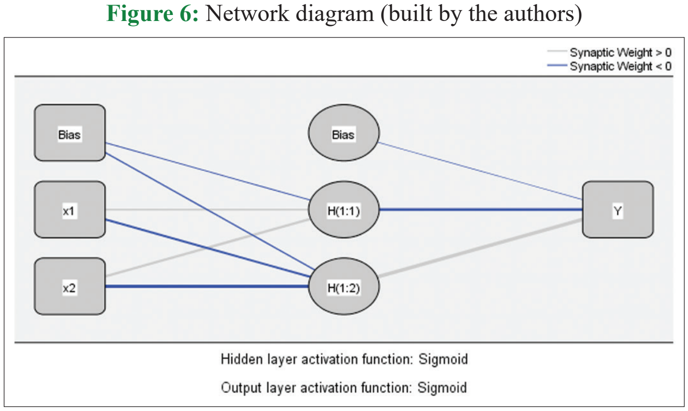
### 5.1 Neural Network Modeling and Forecasting of Sustainable Development and Energy Efficiency of the Russian Economy

In the context of studying the effectiveness of the implementation of sustainable development goals in Russia, a neural network (Multilayer Perceptron) was built with two neurons at the input and one displacement neuron, two neurons on the hidden layer and one displacement neuron (Figure 6). An alternative network with three neurons on the hidden layer showed a higher prediction error, as a result of which it was rejected.

**Table 1: An array of initial data for forecasting sustainable development and energy efficiency of the Russian economy (Federal State Statistic Service, 2020)**

| Year | Greenhouse gas emissions per unit of GDP, tonnes per mln. rub. | Energy intensity of gross domestic product, kg of oil equivalent per 10 thou. rub. | Electricity from renewable energy sources (%) |
|---|---|---|---|
| | Y | $x_1$ | $x_2$ |
| 2012 | 31,5 | 129,7 | 15,3 |
| 2013 | 28,6 | 125,9 | 17,1 |
| 2014 | 26,4 | 126,8 | 16,4 |
| 2015 | 25,2 | 129,6 | 15,8 |
| 2016 | 24,4 | 131,6 | 17 |
| 2017 | 23,4 | 131,9 | 17 |
| 2018 | 21,4 | 131,6 | 17,3 |

**Figure 6:** Network diagram (built by the authors)




The network is an undirected graph that connects neurons of different layers by synapses. Negative synaptic weights, which describe the nature of the connection between neurons, reflect the effect of the inhibitor, while positive synaptic weights, the effect of the driver, which accelerates and enhances the effect on the neuron.

The training sample covered 85.7% of observations, the test sample - 14.3%. The error of the sum of squares for the training sample was 0.121, for the test sample it was 9.092E-7, that is possible to infer about a well-trained neural network that can be used to predict sustainable development indicators and ensure the energy efficiency of the Russian economy. Thus, taking into account the weights, a prognostic model was built based on the sigmoidal function:

$$H_{1:1} = \text{Sigmoid}\ (0{,}953*x_1 + 1{,}056*x_2 - 0{,}310) = 1/(1+e^{-(0{,}953*x1 + 1{,}056*x2 - 0{,}310)}),$$

$$H_{1:2} = \text{Sigmoid}\ (-0{,}998*x_1 - 1{,}785*x_2 - 0{,}385) = 1/(1+e^{-(-0{,}998*x1 - 1{,}785*x2 - 0{,}385)}),$$

$$Y = \text{Sigmoid}\ (-1{,}694*H_1 + 2{,}160*H_2 - 0{,}134) = 1/(1+e^{-(-1{,}694*H1 + 2{,}160*H2 - 0{,}134)}).$$

Based on the modeling results, trends in sustainable development of the Russian economy were identified (Figure 7).

As a result, the predictive model describes the actual observations of the dependent variable Y by 66% and makes it possible to infer about the further reduction of greenhouse gas emissions in Russia and the improvement of the ecological situation in the country.

The predictive model is supplemented with a regression analysis tool (Table 2). The forecast is based on the construction of a multiple linear regression equation, where the predicted values of Y* were the dependent variable (obtained as a result of neural network). The model is characterized by high quality ($R^2$= 0.9956), high significance of regression coefficients ($P < 0.05$), which makes it possible to apply it for the purpose of state regulation of sustainable economic development in the country.

In accordance with the results obtained, the multiple regression equation is:

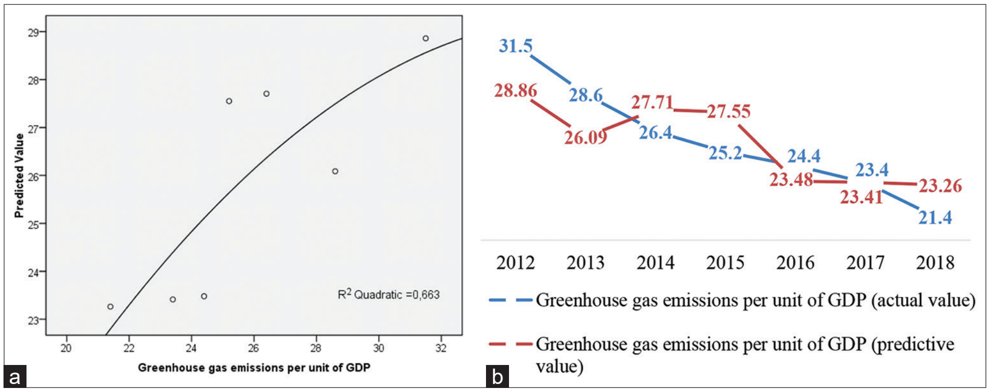
$$Y^* = 130{,}6586 - 0{,}4868*x_1 - 2{,}5267*x_2.$$

When interpreting the revealed dependence, on the one hand, it is necessary to take into account a stable GDP growth, an increase in industrial production, which is certainly accompanied by an increase in the energy intensity of GDP. In this regard, the proposed model implies a further increase in energy consumption, but not more than 132 kg of oil equivalent per 10 thou. rub. On the other hand, awareness of the importance of implementing the principles of "green industry" will undoubtedly contribute to an increase in the share of electricity produced using renewable energy sources. Our predictive model takes into account alternative scenarios for the development of "green" industry and energy in Russia. In this

**Table 2: Predicting the direction of sustainable development and energy efficiency of the Russian economy**

| Regression Summary for Dependent Variable: Y* R=0.99782069 $R^2$=0.99564612 Adjusted $R^2$=0.99346918 F (2,4)=457,36 P<0.00002 Std. Error of estimate: 0.19151 | | | | | | |
|---|---|---|---|---|---|---|
| | b* | Std.Err. - of b* | b | Std.Err. - of b | t (4) | P-value |
| Intercept | | | 130,6586 | 4,35205 | 30,022 | 0,000007 |
| x1 | −0,4949 | 0,03336 | −0,4868 | 0,03281 | −14,834 | 0,000120 |
| x2 | −0,7959 | 0,03336 | −2,5267 | 0,10592 | −23,854 | 0,000018 |

**Figure 7:** Forecasting the volume of greenhouse gas emissions per unit of GDP in Russia, tonnes per mln. rub (a) The ratio of the predicted and actual values (b) Schedule changes of actual and predicted values




regard, Table 3 calculates the expected directions of changes in the indicators of sustainable development and energy efficiency of the Russian economy.

Figure 8 shows the dynamics of greenhouse gas emissions per unit of GDP (Y*) depending on the share of electricity from renewable energy sources ($x_2$), the level of which in perspective can be equal to 18-21%. As a result, 4 scenarios of further sustainable economic development are presented.

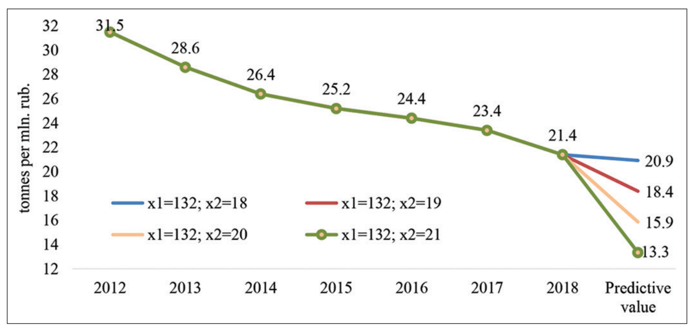
Thus, the proposed model can be taken into account by governmental authorities in order to regulate energy efficiency and sustainable economic development in Russia. There is a need for further, possibly more active stimulation of the country's enterprises to introduce the principles of "green industry," to introduce new technologies that can alleviate the negative burden on the environment.

## 5.2. Comparative Analysis of Sustainable Development and Energy Efficiency of Petrochemical Industries in Russia

Sustainable development and energy efficiency indicators for two types of production are calculated using formulas (4) - (6) and are presented in Table 4.

Thus, it should be noted that the energy efficiency of petrochemical industries is growing, and the negative impact on the environment is gradually decreasing. However, the best indicators are shown by the production of coke and petroleum products, which is due, in particular, to the significant investments of the industry's enterprises in technological innovation. According to statistics, the innovative activity of chemical production in 2018 amounted to 29.8% of industry organizations engaged in innovative activities, for the

**Figure 8:** Alternative scenarios for sustainable economic development in Russia (the volume of greenhouse gas emissions per unit of GDP, tonnes per mln. rub.)




production of coke and petroleum products - 31%; the volume of expenditures on technological innovations also prevails for the latter - 123,789.2 million rubles. in comparison with 67 220.2 million rubles for chemical plants (Higher School of Economics, 2020). As a result, there are better environmental indicators for the production of coke and petroleum products. The industry has achieved positive results in terms of reducing waste for every 1,000 rubles of goods and services shipped, a reduction of 88.4% over 13 years (more than eightfold). The process of transition to sustainable development is more complicated at the chemical enterprises of the country.

Industrial sectors, due to the specifics of production processes, technological features, are distinguished by the intensity of consumption of energy resources, the formation of production waste, and the level of environmental pollution. Diagnostics of petrochemical industries covers an assessment of the links between the noted indicators in two large manufacturing industries - chemical production and production of coke and petroleum products (Tables 5 and 6).

**Table 3: Predicting values for Y***

| Indicators | b-Weight | Value | b-Weight - * Value |
|---|---|---|---|
| $x_1$ | −0,48679 | 132,0000 | −64,2563 |
| $x_2$ | −2,52674 | 18,0000 | −45,4813 |
| Intercept | | | 130,6586 |
| Predicted | | | 20,9210 |
| $x_1$ | −0,48679 | 132,0000 | −64,2563 |
| $x_2$ | −2,52674 | 19,0000 | −48,0081 |
| Intercept | | | 130,6586 |
| Predicted | | | 18,3943 |
| $x_1$ | −0,48679 | 132,0000 | −64,2563 |
| $x_2$ | −2,52674 | 20,0000 | −50,5348 |
| Intercept | | | 130,6586 |
| Predicted | | | 15,8675 |
| $x_1$ | −0,48679 | 132,0000 | −64,2563 |
| $x_2$ | −2,52674 | 21,0000 | −53,0615 |
| Intercept | | | 130,6586 |
| Predicted | | | 13,3408 |

**Table 4: An array of initial data for the study of sustainable development and energy efficiency of the Russian petrochemical industry (calculated by the authors according to the Federal State Statistic Service [2020])**

| Year | Manufacture of chemicals and chemical products | | | Manufacture of coke and refined petroleum products | | |
|---|---|---|---|---|---|---|
| | $x_1$ | $x_2$ | $x_3$ | $x_1$ | $x_2$ | $x_3$ |
| 2007 | 0,0371 | 0,3961 | 4,8785 | 0,0152 | 0,3644 | 0,8344 |
| 2008 | 0,0248 | 0,2677 | 2,0576 | 0,0118 | 0,2737 | 0,5027 |
| 2009 | 0,0342 | 0,3129 | 1,9403 | 0,0133 | 0,2492 | 0,5636 |
| 2010 | 0,0277 | 0,2344 | 1,8146 | 0,0109 | 0,2082 | 0,4827 |
| 2011 | 0,0210 | 0,1866 | 2,3114 | 0,0089 | 0,1629 | 0,3733 |
| 2012 | 0,0198 | 0,1744 | 0,7416 | 0,0082 | 0,1443 | 0,4024 |
| 2013 | 0,0192 | 0,1778 | 0,8801 | 0,0080 | 0,1221 | 0,2487 |
| 2014 | 0,0172 | 0,1720 | 0,6041 | 0,0067 | 0,0917 | 0,2628 |
| 2015 | 0,0135 | 0,1333 | 0,5494 | 0,0064 | 0,0863 | 0,2124 |
| 2016 | 0,0148 | 0,1471 | 0,5544 | 0,0061 | 0,0882 | 0,0786 |
| 2017 | 0,0142 | 0,1456 | 1,4122 | 0,0056 | 0,0821 | 1,6513 |
| 2018 | 0,0118 | 0,1090 | 1,4077 | 0,0045 | 0,0602 | 0,1177 |
| 2019 | 0,0122 | 0,1112 | 1,2879 | 0,0050 | 0,0703 | 0,0968 |
| Growth rate, % | −67,25 | −71,93 | −73,60 | −67,30 | −80,71 | −88,40 |

**Table 5: Correlations (Manufacture of chemicals and chemical products). Marked correlations are significant at P<0,05000 n=13**

| | Means | Standard deviation | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|---|---|
| $x_1$ | 0,020583 | 0,008242 | 1,000000 | 0,974137 | 0,753628 |
| $x_2$ | 0,197549 | 0,084351 | 0,974137 | 1,000000 | 0,812037 |
| $x_3$ | 1,572295 | 1,162961 | 0,753628 | 0,812037 | 1,000000 |

**Table 6: Correlations (Manufacture of coke and refined petroleum products). Marked correlations are significant at P<0,05000 n=13**

| | Means | Standard deviation | $x_1$ | $x_2$ | $x_3$ |
|---|---|---|---|---|---|
| $x_1$ | 0,008507 | 0,003358 | 1,000000 | 0,979132 | 0,247932 |
| $x_2$ | 0,154120 | 0,093786 | 0,979132 | 1,000000 | 0,280056 |
| $x_3$ | 0,448261 | 0,420389 | 0,247932 | 0,280056 | 1,000000 |

In the first case, speaking about chemical industries, it is necessary to state a high degree of closeness of the relationship between indicators of energy intensity, production waste and air polluting emissions. All pair correlation coefficients exceed 0.7. In the second case, a weak influence of the level of waste on energy consumption by enterprises producing coke and petroleum products was revealed, the pair correlation coefficients are below 0.3. As a consequence, it can be assumed that these wastes are generated mainly outside of energy-intensive production processes. The correlation between energy intensity and air emissions is high.

Shown in Figure 9 surface diagrams confirm the nature of the interdependence of the studied indicators of sustainable development in the noted industries. In Figure 9a, the high quality of the surface fit to the initial data characterizing certain aspects of the sustainable development of chemical industries is evident.

Thus, petrochemical industries are characterized by heterogeneous trends in terms of sustainable development. For chemical industries, a more interconnected structure of indicators has been identified, which allows a systematic approach to the construction of production processes that meet the principles of "green industry." This need is due to the high negative external effect arising from the activities of enterprises in the industry - a relatively high level of waste, polluting emissions and energy consumption.

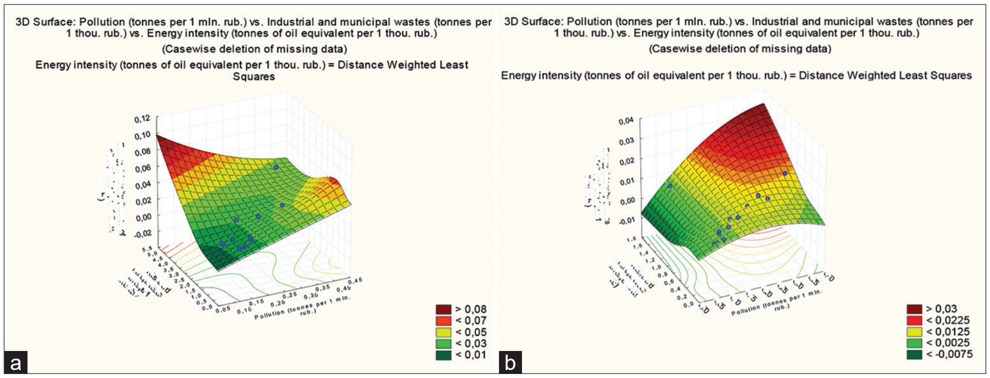
Enterprises for the production of coke and petroleum products are characterized by more energy efficient technological processes, as evidenced by the indicator of specific energy intensity, which is 2.5 times lower than the analogous indicator of the functioning of chemical plants.

Comparative analysis of sustainable development trends in the two industries allows us to state higher rates of modernization of coke and oil products production, which is confirmed by the comparatively better growth rates of the analyzed indicators (Table 4) and higher innovative activity of the industry enterprises.

From the point of view of financial state support for the technological modernization of petrochemical enterprises, there is a preference in favor of chemical production: in 2018, budgets of different levels allocated 622 million rubles for technological innovations in the industry (1% of the total expenditures on technological innovations in the industry). Enterprises producing coke and petroleum products carry out technological modernization mainly on their own (Higher School of Economics, 2020). The study of state support for technological modernization in the Russian industry as a whole allows us to state that there is little attention to petrochemical industries and special attention to the production of metal products (about 37.1 billion rubles), computers (about 16 billion rubles), aircraft and space vehicles (about 10, 5 billion rubles) and other areas of production (Higher School of Economics, 2020).

In general, it is necessary to state the unconditional progress of the Russian petrochemical industry in the context of energy-saving and sustainable development. The noted decrease in specific indicators

**Figure 9:** Three-dimensional surface chart, the approximation method of least squares (a) Manufacture of chemicals and chemical products (b) Manufacture of coke and refined petroleum products




for the period 2007-2019 is the result of effective state regulation of industrial development in the country. At the same time, the uneven greening of the petrochemical industry requires the state to differentiate incentive mechanisms depending on the level of negative load generated by industrial production.

## 6. CONCLUSION

Thus, the state priorities in the petrochemistry of Russia have been investigated. As a result of an analytical study of the specifics of sustainable development of the Russian economy and trends in the energy-saving development of petrochemical industries, through the use of a wide methodological toolkit, the following conclusions were formulated and a number of results were obtained:

1. Priority areas for the state in terms of financing, among others, are rational use of natural resources and energy efficiency, energy conservation, nuclear energy. Financial support for the energy sector (73.5 billion rubles of budgetary funds) prevails in comparison with the financing of rational use of natural resources, which is explained by the predominance of energy consumption by industrial enterprises over the extraction of natural resources for production needs (in particular, water). In general, there is a weak state support for the technological modernization of petrochemical production in the context of industrial sectors in Russia
2. Sustainable development within the macroeconomic system is accompanied by an increase in the energy intensity of GDP (by 1.44% during 2012-2018), but at the same time by a gradual transition to renewable energy sources (by 12.81% over the same period). In the latter case, the trend is unstable, but on the whole, a positive transformation of the country's economy should be noted
3. Proposed a neural network model trained on the indicators of sustainable and energy-efficient development of the Russian economy. The neural network has a low level of errors, which made it possible to formalize the relationship between the indicated dependent variable and predictive variables (GDP energy intensity and the share of electricity from renewable energy sources)
4. Based on the results of neural network modeling, a prognostic model has been built, which, in combination with a regression analysis tool, made it possible to calculate the future values of the volume of greenhouse gas emissions per unit of GDP in Russia. The calculation was made for four alternative development scenarios, further increase in energy intensity is allowed (up to 132 kg of oil equivalent per 10 thou. Rub.) and the share of electricity from renewable energy sources in the range of 18-21%. As a result, the dependent variable will continue to decline to 20.92, 18.39, 15.87 or 13.34 tons per million rubles of GDP (the effect will be 0.5, 3, 5.5 or 8.1 tons per million rubles of GDP respectively)
5. Specific indicators of sustainable development and energy efficiency of petrochemical industries were calculated and evaluated. Higher values of indicators were recorded for chemical industries, which is explained by more complex technological processes, chemical reactions, a wide variety of types of raw materials and obtained materials, which generally requires differentiation of technologies, equipment, and resources. As a result of the application of the method of correlation analysis, the features of the greening of petrochemical industries in Russia were revealed: more energy efficient technological processes are typical for enterprises producing coke and oil products than for chemical industries; also revealed a higher rate of modernization of production of coke and petroleum products, leading to a high rate of reduction of waste and air polluting emissions.

In general, the need for more focused attention of the state on petrochemical industries and their technological modernization is summarized. Within the petrochemical industry, special attention should be paid to chemical industries that demonstrate high specific indicators of energy consumption and environmental pollution. Sustainable development of the industry is carried out at a relatively slow pace, especially in terms of air pollution; the best indicators in dynamics and over the years were noted for the production of coke and petroleum products. The growth in the energy efficiency of the latter is due to the significant investments of industry enterprises in technological innovation.

The results obtained can be taken into account in the activities of national regulatory and administrative authorities at different levels, the proposed specific indicators used as the basis for a comparative analysis of petrochemical industries can be included in the methodology for assessing the achievement of the Sustainable Development Goals, including in terms of ensuring the energy efficiency of the economy. The Russian state should, first of all, increase support for chemical industries, and direct real efforts to modernize technologies, which will contribute to a more active transition of the industry to sustainable development. The proposed predictive models can also be included in the strategic initiatives of the state regulating the development of industry in the country, and taken as the basis for the intensification of stimulating the transition of chemical enterprises to the "green industry." These initiatives are the "Energy Strategy of the Russian Federation for the Period up to 2035," "Strategy of scientific and technological development of the Russian Federation," "The strategy of spatial development of the Russian Federation for the period up to 2025" and others.

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