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Optimization Model for the Russian Electric Power Generation Structure to Reduce Energy Intensity of the Economy

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ABSTRACT

In the context of high energy intensity of the country's economy, contributing to a decrease in the industry competitiveness of the Russian Federation, it is relevant to develop scientific approaches to energy efficiency provision. The article is aimed at stimulating the optimal structure of electric power generation in Russia, promoting energy conservation and lowering energy intensity of the economy. The Cobb-Douglas production function was used to determine the dependence of the gross electric output on such production factors as labor costs and capital. Based on the expert evaluation method, the sources of electricity generation were differentiated according to the level of labor intensity. An optimization model has been developed for electric power generation structure in Russia in the context of actual energy generation sources: Nuclear power plants; natural gas fired thermal power plants, coal and fuel oil fired power plants; hydropower plants; solar power plants; wind power plants; tidal power plants; and biofuel power plants. The percentage changes in the consumption of energy resources and power generation, ensuring a decrease in the energy intensity of the Russian Gross Domestic Product by 19.1%, are argued. The system of optimization measures has been substantiated; their practical implementation will contribute to the steady decline in energy intensity of the Russian economy, effective energy consumption and the growth of the country's energy potential, with regard to ensuring structural changes in the energy sector.

Keywords: Energy Intensity of the Russian Economy, Energy Resources, Optimization Model for Electric Power Generation Structure, Power Industry, Economic Energy Efficiency
JEL Classifications: Q4; L16; L52

1. INTRODUCTION

In modern conditions, as well as in the long run, the fuel and energy complex (FEC) plays a crucial role in the economy of the Russian Federation and the well-being of citizens (Vasiljeva, 2017). The FEC forms a significant share of the national income of the country and the state budget. To maintain the increase in these revenues, the state energy policy should be directed rather at an intensive, than at an extensive, economic growth of the country's FEC, which includes both efficiency gains in the fuel and energy sectors, and decrease in energy intensity of the economy (Baev, 2012; Ang and Goh, 2018; Mishra and Datta-Gupta, 2018; Werner, 2017; Kapustin and Grushevenko, 2018).

Despite the fact that the consumption of energy resources over the period of 1991-2017 decreased by 19%, at purchasing power parity the Russian Federation ranks second in the world in terms of energy intensity of the economy (as of 2017, it made 0.221 koe/$2015p), which is almost 2 times higher than the world average, according to Enerdata Company (BP, 2002; BP, 2018; Enerdata, 2018).

To put that into context, average energy intensity level makes 0.098 koe/$2015p (OECD), 0.078 koe/$2015p (European Union) and 0.101koe/$2015p (G7). In addition, it should be noted that in 1990-2008 energy intensity level of the Russian economy decreased by

30%, and in 2008-2017 there is 3.4% increase observed (Enerdata, 2018). And this is under the conditions of the state program "Energy saving and energy efficiency increase for the period up to 2020" adopted in 2010 by the Ministry of Energy, the main goal of which is to reduce energy costs per unit of GDP by 40% by 2020 (RF Government Executive Order No. 2446-p, 2010).

The following main factors of energy intensity should be highlighted for the Russian economy: Climatic conditions, immensity of the country's territory, availability of energy resources, a high proportion of energy-intensive industries in the economy.

A cold climate is the most important climatic feature of Russia. A tendency toward climate warming by 0.45°C and a decrease in wind loads have been observed in the country over the past 10 years, which, in case of its persistence, can result in reduced heating period duration in the long run. This will significantly contribute to energy saving in the country (Roshydromet, 2018). But nevertheless, the average annual temperature remains below 0°C in the country. (Russian Federal Service for Hydrometeorology and Environmental Monitoring, 2018). In comparison with other countries, Russia is far ahead in terms of the heating season duration and the proportion of the population living in areas with a negative average annual temperature (NOAA's National Centers for Environmental Information, 2018). However, the GDP energy intensity of the countries located in similar geographical conditions (Canada, Finland, Scandinavian countries), on average, is 2 times lower than in Russia (RF Government Executive Order No. 2446-p, 2010). Despite the fact that Russia is significantly inferior to other countries in terms of population density (being the 218th in the world - 8.79 people per km^2 (Statistics Times, 2018), the country's territory is the largest in the world - 17,098,250 m^2 (Index Mundi, 2018), which determines the presence of energy capacity several times higher than in other countries of the world. For example, in the territories of Siberia, electricity is transported along the longest power lines in the world. At the same time, annual electricity losses are about 14% of electricity (REW, 2018; PJSC Rosseti, 2018).

The availability and low cost of energy resources in the domestic market is also one of the key factors of energy intensity of the Russian economy. In January 2018 the average cost of electricity in Russia for the population was 0.08 dollars per 1 kWh, whereas for comparison in France and the UK the prices are almost the same - within the range of 0.21-0.22 dollars, and the most expensive electricity in Germany and Denmark costs 0.38 dollars per kilowatt-hour (FSSS, 2018; Eurostat, 2018). The cost of gas was USD 95.2 per 1000 m^3, while in France and the UK it amounted to USD 834.5 and 575.5, respectively, making USD731.6 in Germany and USD 1050 in Denmark (Sputnik Latvija, 2018). It is affordable and cheap fuel and electricity in the domestic market that is one of the main objective reasons for the high energy intensity of the Russian GDP, the main brake on energy conservation. Energy-saving technologies such as heat pumps, heat accumulators, wind power generation remain exotic ones, they do not find wide practical application, remain unknown and unclaimed.

The structure of Russian economy is a determining destructive factor of energy efficiency; it is characterized by a high proportion of energy-intensive industries - up to 40% in the GDP structure, consuming more than 80% of primary fuel and more than 50% of electricity (FSSS, 2018). It should be noted that this the factor is primarily associated with a low level of physical and moral depreciation of equipment in the industrial sector of the Russian economy - up to 60%, which ensures up to 9% of energy losses from the total volume of consumption (FSSS, 2018).

Maintaining a high level of energy intensity of the economy relative to other countries of the world provokes a low level of competitiveness of the Russian industry, causes the risk of reliability guarantees for international energy supplies and a threat to the country's environmental safety. And taking into account the experts' opinions that in Russia the gas and oil reserves will last only for 40-50 years (Pravda.ru, 2018), the energy intensity decline becomes urgent in the Russian economy as part of energy efficiency and energy saving strategy. However, achieving the goal as to the set parameters of the strategy seems problematic due to the lack of predictable structural changes in the economy (Cheng et al., 2018).

Optimization of the FEC structure can be the basis for reducing energy intensity of the Russian economy in modern conditions. As of 2017, the structure of domestic consumption of primary fuel and energy resources is formed by gas (51.9%), oil (20%), coal (14.8%), electricity from hydro and nuclear power plants (12.2%), and other types of energy resources (1.1%) (MERF, 2018). At the same time, 45% of gas production is used in industry, 35% is consumed at TPPs and 10% in the housing and public utility sector (Greenologia.ru, 2018). In this case, the decrease in energy intensity through gas consumption minimization is possible by reducing the proportion of gas used by TPPs, i.e., by optimizing the structure of the power industry. In the structure of oil consumption, about 65% is occupied by the production of motor gasoline and diesel fuel (MERF, 2018). Transition to electric cars is an alternative to reducing the consumption of this part of oil, which necessitates the optimization of the electric power generation structure. The main goal of coal consumption is to generate electricity (28%) (MERF, 2018).

Proceeding from the above statistical data, the optimization of the electric power generation structure will directly reduce the cost of electricity generation, and therefore, decrease the consumption of gas and coal for electricity generation used by TPPs and lower oil consumption by reducing the use of gasoline by cars and increasing the amount of electricity used, the cost of which is significantly lower.

In this regard, the purpose of the research was to develop an optimal model of the Russian energy system structure ensuring the decline in energy intensity of the economy. In the course of the investigation, the following research tasks were set and solved: To identify the factors decreasing economic energy intensity in the Russian Federation; to define and substantiate the optimization structure of the country's energy system ensuring energy saving at the present stage of development; to justify the effective level for consumption reduction by type of energy resources in the domestic market; to rationalize the main directions for increasing energy efficiency in Russia with the existing level of energy generation.

2. MATERIALS AND METHODS

The methodological framework of the research was made by the optimization problem, using the Cobb-Douglas production function and expert evaluation with the Kuhn-Tucker theorem applied.

The Cobb-Douglas function was used to build production constraints for various types of electricity - models of gross electric output vs. production factors – labor and capital. The Cobb-Douglas function is written as follows (Topaj and Mirschel, 2018):

$$Y = X_1^{\alpha} \cdot X_2^{\beta} \quad (1)$$

Where Y – total production;
X_1 - labor input indicator;
X_2 – capital input indicator;
α,β - output elasticities of factors X_1 and X_2, respectively.

Expert evaluation was used to rank electricity sources by the level of labor input. The implementation of the expert evaluation methodology in the study provides for the formation of a working group of 10 people -employees of the Center for Environmental Policy of Russia; ensuring the representativeness of the survey results by providing the experts' competence and opinion consistency; and the interpretation of results. The rank "1" was assigned to the source of electricity with the highest labor input.

The degree of expert opinion consistency was evaluated by the coefficient of concordance (formulas 2-5):

$$W = \frac{12\sum_{j=1}^{n} d_j^2}{m^2\left(n^3 - n\right) - m\sum_{i=1}^{m} T_i} \quad (2)$$

$$d_j = S_j - \frac{\sum_{j=1}^{n} S_j}{n} \quad (3)$$

$$S_j = \sum_{i=1}^{m} R_{ij} \quad (4)$$

$$T_i = \sum_{l=1}^{L} (t_l^3 - t_l) \quad (5)$$

Where W is a coefficient of concordance;
m - the number of experts;
n - the number of criteria;
d_j - the deviation of the sum of ranks by the j-th criterion from the mean sum of ranks in the sample;
S_j – the sum of ranks by the j-th criterion;
R_{ij} – a ranking matrix;
T_i – the results of intermediate calculations in case of tied ranks;
L – the number of tied rank groups;
t_l – the number of tied ranks for each expert.

The Chaddock scale was used to interpret the values of the coefficient of concordance. According to this scale, the value of the correlation coefficient, which in the study was the coefficient of concordance, ranging from 0.1 to 0.3 indicates a weak relation between the indicators, the range of 0.3-0.5 suggests moderate relation, the range of 0.5-0.7 being indicative of a noticeable, 0.7-0.9 –of strong, and 0.9-0.99 of very strong relation (Rousseau et al., 2018). The values of the coefficient of concordance being ≥0.7 indicate the existence of a significant relationship between expert estimates and consequently, the high degree of their opinion consistency. If the value of the coefficient of concordance is <0.7 expert opinion consistency is at a low level.

The optimization model was used to simulate the electric power generation structure, which minimizes the total cost of electricity generation. For this purpose the Kuhn-Tucker theorem was used, enabling to solve linear programming problems with constraints in the form of equalities and inequalities (Sumin, 2012).

According to the theorem, vector X^* is a solution to the problem if and only if there is vector $\Psi^*$and while satisfying the inequalities $X^* \geq 0$, $\Psi^* \geq 0$ for all $X \geq 0$, $\Psi \geq 0$ point (X^*, Ψ^*) is a saddle point of the Lagrangian $L(X, \Psi) = f(X) + \sum\lambda_i (b_i - q_i(X))$and function $f(X)$ is concave for all $X \geq 0$, function $q_i(X)$ is convex (Tanaka, 2015).

3. RESULTS

For the purpose of building an optimization model aimed at minimizing the total cost of electricity generation, the authors applied the Kuhn-Tucker theorem (Tanaka, 2015) enabling to find the minimum values of the function parameters for the established criteria of the target indicator.

The optimization facilities include the electricity generation sources: Natural gas fired thermal power plants, coal-fired thermal power plants, fuel oil-fired thermal power plants, hydropower plants, nuclear power plants, wind power plants, solar power plants, biofuel power plants and tidal power plants. The cost of electricity production became the optimization criterion (Figure 1) (Khokhlov, 2017; Degtyariov, 2017; Kissin and Rakul, 2018; Renewable energy, 2018; EY, 2018; RSEU Climate Secretariat, 2018).

It can be concluded on the basis of the data of Figure 1 that with regard to the average electricity production costs per 1 kWh hydropower plants (RUB 0.08) have the lowest costs. Also, there are low costs for gas-fired thermal power plants (RUB 0.4), and nuclear power plants (RUB 0.4). The Biofuel power plants (RUB 0.78 rubles per 1 kWh) and solar power plants (RUB 0.75) are most cost intensive in terms of power generation. Electricity production at hydropower plants is most efficient based on this indicator, which will allow for reduction in energy intensity of the economy. However, on the other hand, production volumes are limited by the production capabilities.

The Cobb-Douglas production function, reflecting the dependence of the production volumes on the production factors – labor and capital, was used to describe the production capabilities and determine the production potential.

Figure 1: Average electricity production costs per 1 kWh in the Russian Federation as of 2017, RUB

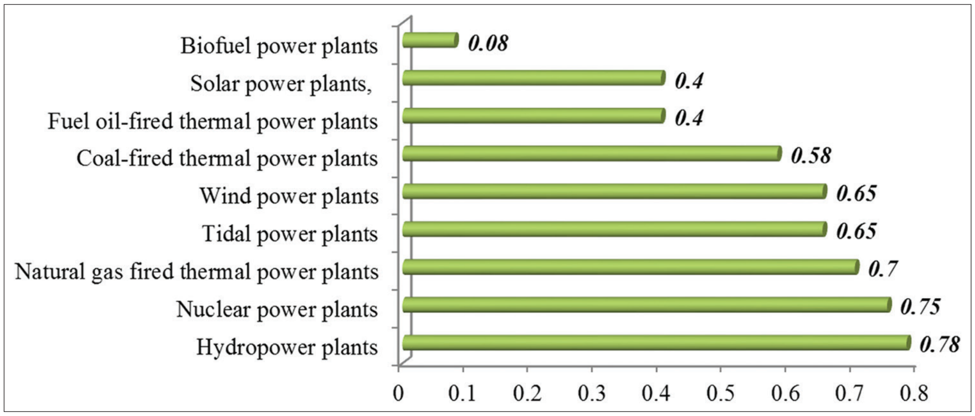


Table 1: Matrix for experts' competence evaluation in the field of estimating labor input in the electric power generation industry

Experts	E 1	E 2	E 3	E 4	E 5	E 6	E 7	E 8	E 9	E 10
E 1	-	0	1	1	0	0	1	1	1	1
E 2	1	-	1	1	1	1	0	1	1	1
E 3	1	1	-	0	1	1	1	1	0	1
E 4	1	1	1	-	1	1	1	0	1	1
E 5	1	1	1	1	-	1	1	1	1	1
E 6	0	1	1	1	1	-	1	1	1	1
E 7	1	1	1	1	1	0	-	1	1	1
E 8	1	0	1	1	0	1	0	-	1	1
E 9	1	1	1	1	1	1	1	1	-	1
E 10	1	1	1	1	1	1	1	1	1	-
Sum of positive estimates	8	7	9	8	7	7	7	8	8	9
Competence coefficient	0.9	0.8	1	0.9	0.8	0.8	0.8	0.9	0.9	1

Such a production factor as the land, the availability of natural resources, becomes important in the formation of the production potential for electricity generation using non-renewable sources (Orazalin and Mahmood, 2018). Since this factor is not taken into account in the classical Cobb-Douglas production function, it is expedient to add it with the 3rd factor – an indicator of the availability of natural resources, expressed by proven reserves of oil, gas and coal in Russia.

For nuclear power plants, natural resource stocks are estimated by the reserves of uranium, which, according to experts' estimates, will suffice for 100 years (Pravda, 2014; Aftershock, 2016). Gas reserves are estimated to last for 80 years (Moiarussia, 2018), coal reserves will be enough for 500 years (TBC, 2017). Since fuel oil is a product that is formed as residues from the oil topping, the resources for fuel oil-fired TPP are estimated as oil reserves which, according to experts, will last for 30 years (Moiarussia, 2018).

For non-traditional energy sources, the reserves of natural resources $\rightarrow \infty$, therefore, there are no restrictions on material resources in the production function for non-traditional sources.

The labor supply indicator is accounted for in the production model as it is required to assess the availability of specialists for the production of energy of various kinds. Due to the limited official statistical information about the level of specialization of these specialized employees and about measuring the labor input level in electricity generation, the models are built proceeding from the following logic: Specialists working at power plants major in energy engineering no matter what industry energy sector they work. Therefore, the labor supply provision was understood as a total manpower for all electricity generation sectors, but with regard to the differences in the labor input level depending on the energy sector, which affects energy intensity of the economy.

Official statistical information on labor cost breakdown by electricity generation sectors is also absent; therefore, an expert evaluation of the ranking of electricity sources by labor costs was carried out. The highest labor intensity corresponded to the rank "1" and the lowest equated to the rank "9". The experts (E) were 10 members of the Project Center for Energy Efficiency and Construction, a professional public environmental organization that is involved in ensuring energy efficiency. (Delovaya Rossiya LLC, 2018).

The adequacy and significance of the evaluation results depend on the experts' competence (Tikhomirova and Matrosova, 2016). The competence coefficient is used in this study to assess the experts' competence. Each expert was suggested to rank the feasibility of including another expert in the working group by "0" or "1". The rank "0" meant a negative assessment of the need to include the evaluated expert in the group as a result of his/her low competence; "1" corresponded to a positive assessment: The experts' competence was at a high level and their inclusion in the working group was appropriate. The results of the expert group competence evaluation are presented in Table 1.

The matrix rank $a_{ij} = 0$, where i is the row number, j is the column number means disagreement of the i-th expert with the inclusion of the j-th expert in the working group to evaluate labor input of electricity generation as a result of the j-th expert's low competence. The rank $a_{ij} = 1$ means the agreement of the i-th expert with the inclusion of the j-th expert in the working group.

The competence coefficient is calculated as the ratio of the actual amount of positive responses to the maximum possible rank "9". The competence coefficient is measured in the range [0; 1]. The higher the coefficient value, the more competent the expert is, according to his/her colleagues – the experts included in the expert group. A level of 0.5 is considered sufficient.

For all experts, the competence coefficient exceeded the value of 0.5, which indicates the feasibility of including all experts in the group for evaluating labor input of electricity generation, their high competence, and the significance of the expert evaluation results.

The assessment of the degree of expert opinion consistency was carried out on the basis of the calculation of the coefficient of concordance, which reflects the tightness of the relationship between the judgments of experts. When operating with the Cheddok scale, the relation with the coefficient of concordance >0.7 is essential. The calculated value of 0.81 indicates a close relationship between expert evaluations, and therefore the representativeness of expert evaluation results.

The conducted expert evaluation revealed that the highest labor intensity in electricity generation is observed at biofuel power plants (ranking on average 1.5), tidal power plants (ranking on average 1.8), solar power stations (3.3) and wind power stations (3.8). That is, when generating energy from alternative energy sources, due to their insufficient development, labor costs are at the highest level.

Lower labor intensity of electricity production is observed at nuclear power plants (ranking on average 5.3), coal-fired thermal power plants (7.5), gas-fired TPP (7.8) and fuel oil fired TPP (8.2). And hydropower plants have the lowest labor intensity of electricity generation (ranking on average 8.8).

The labor intensity is the score at which the higher the value, the higher the potential, that is, there is a direct relationship between the potential and the indicator of ranked labor intensity.

The indicator of investment costs per 100 kW of real power was taken for the evaluation of capital. To account for the capital factor in the production function, the capital intensity indicator was applied, indicating the feasibility of investing in a certain electricity generation method. The initial data for the construction of production functions are given in Table 2.

Natural resource reserves, labor input and capital input are indicators that are used in production functions. Capital input is expressed as a continuous series of data having the inverse effect on the potential (the higher the capital input value, the higher the potential), therefore, the inverse indicator (*1/k*) is used in the function, where k is capital input.

Since all indicators have different dimensions: Cost, natural data, rank, number of years, their values were standardized. The developed production functions are presented in Table 3.

The factor indices of the production functions characterize the elasticity of production volumes (production potential) due to the factors. Thus, the constructed functions demonstrate that the electricity generation potential is most dependent on the availability of natural resources (for traditional sources of electricity) and capital (to a greater extent for alternative sources). This is explained by the fact that owing to the underdevelopment of alternative energy sources in Russia at this stage their development requires substantial capital expenditures.

Taking into account deterministic production capacities, an optimization model of electric power generation structure was built:

$$\begin{cases} L = \rho_1 \cdot \theta_1 + \rho_2 \cdot \theta_2 + \ldots + \rho_n \cdot \theta_n \to min; \\ \rho_i = \dfrac{V_i}{V},\ \rho_i \in [0;1]; \\ \rho_1 + \rho_2 + \ldots + \rho_n = 1; \\ V_1 + V_2 + \ldots + V_n = V; \\ V = D,\ V_i \le Y_i; \\ Y_i(1) = X_1^{\alpha} \cdot X_2^{\beta} \cdot X_3^{\gamma}; \\ Y_i(2) = X_2^{\beta} \cdot X_3^{\gamma} \end{cases}$$

L – total costs of electricity generation;

ρ_i – proportion of the i-th electricity generation source in the structure of total production;

Table 2: Performance indicators of the energy resource market

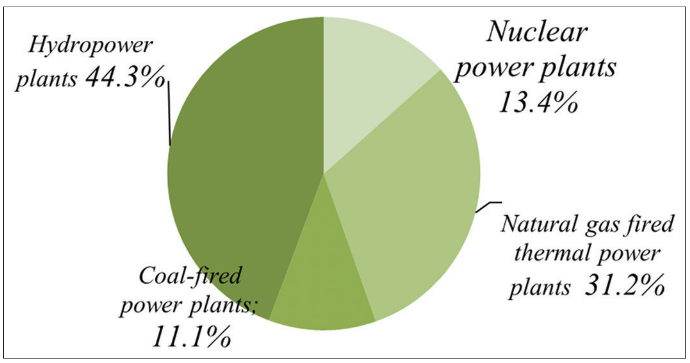
Power plant type	Proved natural resource reserves, years	Labor input, rank	Capital input, (average investment costs), RUB mln per 100 kW of real power
Nuclear power plants	≈100	5.3	0.52
Natural gas fired thermal power plants	≈80	7.8	0.3
Coal-fired power plants	≈500	7.5	0.52
Fuel oil power plants	≈30	8.2	0.41
Hydropower plants	→∞	8.8	0.73
Solar power plants	→∞	3.3	0.66
Wind power plants	→∞	3.8	0.79
Tidal power plants	→∞	1.8	0.92
Biofuel power plants	→∞	1.5	0.5

Table 3: Levels of financial risk indicators for oil enterprises

Power plant type	Production function
Nuclear power plants	$Y = X_1^{0.4} X_2^{0.1} X_3^{0.5}$
Natural gas fired thermal power plants	$Y = X_1^{0.5} X_2^{0.2} X_3^{0.3}$
Coal-fired power plants	$Y = X_1^{0.5} X_2^{0.1} X_3^{0.4}$
Fuel oil power plants	$Y = X_1^{0.4} X_2^{0.2} X_3^{0.4}$
Hydropower plants	$Y = X_2^{0.4} X_3^{0.5}$
Solar power plants	$Y = X_2^{0.1} X_3^{0.9}$
Wind power plants	$Y = X_2^{0.2} X_3^{0.8}$
Tidal power plants	$Y = X_2^{0.1} X_3^{0.9}$
Biofuel power plants	$Y = X_2^{0.1} X_3^{0.9}$

Legend: У - Standardized production volumes X_1 – Material factor (availability of natural resources), X_2 – Labor factor; X_3 – Capital factor. For the latter 5 functions there is no element X_1 - restrictions on material resources, since they characterize renewable energy sources

Figure 2: Optimization structure of electricity generation in the framework of providing energy efficiency of the Russian economy



θ_i – operating cost per unit of the *i*-th type of electricity;
V_i – volumes of production of the *i*-th type of electricity;
V– gross electric output;
D – volumes of domestic electric energy demand;
Y_i - production potential for the *i*-th type of electricity determined by the production function (Table 4);
X_1 – material factor (natural resource reserves);
X_1 - labor factor ($X_3 = R$);
R – ranked labor intensity of electricity generation. The higher the rank, the lower the labor intensity;
X_3 – capital factor ($X_3 = 1/k$);
K – capital intensity of electricity generation;
Y_i (1) – production function for exhaustible energy sources;
Y_i (2)– production function for inexhaustible energy sources ($X_1 \rightarrow \infty$);
α, β, γ – production elasticity coefficients due to material factor, labor and capital input, respectively.

Based on the model, the optimal structural proportions of electricity generation in the Russian Federation are calculated, ensuring reduction in energy intensity of the economy in modern conditions (Figure 2).

The calculated data for the optimization model of electric power structure relative to the actual one are given in Table 4.

4. DISCUSSION

The electricity produced by hydropower plants is the most efficient type of energy: The lowest operating cost indicator per 1 kWh of electricity is 0.08, the lowest labor intensity (ranking 8.8). But this type of electricity has one of the highest capital intensity indicators (0.73 million rubles per 100 kW of actual power). Due to the limited value of the production potential, the use of this type of electricity is also limited. The optimal part of the hydropower electricity, calculated by the optimization model, amounts to 44.3% of the Russian electricity generation market. Gas-fired power plants produce 31.2% of electricity. Nuclear power plants generate 13.4% of electricity. Coal-fired thermal power plants produce 11.1% of electricity. Considering the actual structure of electricity generation as of 2017, the proportion of electricity produced by nuclear power plants should decrease by 5.5%, that produced by thermal power plants should be lowered by 13.9%, and reduction in electric output of coal-fired thermal power plants should make 6.4%. The use of fuel oil fired thermal power plants seems infeasible for the purpose of decreasing the oil consumption volume. At the same time, an increase in electricity generation by 26.9% by hydropower plants is becoming economically beneficial for energy saving at the current stage of the energy industry development in Russia. It should be noted that today the Russian total gross (theoretical) hydropower potential is determined as making 2,900 billion kWh of annual electricity generation or 170 thousand kWh per 1 sq. km of the territory. The technically achievable level of hydropower use is about 70% of the gross (theoretical) hydropower potential, that is, Russia's total technical hydropower potential is 1,670 billion kWh of annual output (Expert RA, 2018). Considering the optimization model of the electric power generation structure, the actual capacity of the hydropower potential should increase by 449.23 billion kWh, which will make 2,119.23 billion kWh.

The implementation of increase in electricity generation by hydropower stations is quite feasible in practice. Russia maintains a leading position in the lists of states with the highest rates of total capacity and power generation at hydropower plants, trailing only China, Brazil, the United States and Canada. The global capacity of hydropower plants and pumped storage hydroelectric power plants exceeded 1,100 GW. The capacity of hydropower plants in the Russian Federation exceeds 50 GW, which is about 20% of the total capacity of power plants in the country (Hydropower of Russia Association of Hydropower Organizations and Workers, 2018). They have a significant advantage in the structure of electricity generation in Russia – a low level of electricity production cost (more than 2 times lower, and payback is by 3-4 times more intense than at TPPs).

Also, HPPs' ability to cover the peaks of energy consumption at the expense of easily controlled power by differentiating the water flow speed is a significant advantage of hydropower as opposed to other types of generation. The implementation of the RusHydro investment program can provide the growth of hydropower potential. Until 2025, it is planned to upgrade 55% of the total

Table 4: Actual and optimization structure of electricity generation

Power plant type	Actual structure as of 2017, %	Optimization structure, %	Structural changes, p.p.
Nuclear power plants	18.9	13.4	−5.5
Gas-fired thermal power plants	45.1	31.2	−13.9
Coal-fired power plants	17.5	11.1	−6.4
Fuel oil power plants	1.0	-	−1.0
Hydropower plants	17.5	44.3	+26.9
Solar power plants	0.1	-	−0.1
Wind power plants			
Tidal power plants			
Biofuel power plants			

fleet of the company's turbines, 42% of the total fleet of generators and 61% of transformers. As a result, it is expected to increase the capacity of hydroelectric power stations by 779 MW and an increase in average annual electricity generation by 1.376 billion kWh (RusHydroPJSC, 2018).

In addition to the modernization of the power plants, the active construction of small damless hydropower plants in Russia, with capacity not exceeding 30 MW and the single hydroelectric unit capacity being less than 10 MW, will also contribute to the increase in hydropower capacity. This method of increasing energy generation in Russia seems to be effective from the point of view that the potential sources of energy for small hydropower sector are quite extensive. These include small rivers, streams, natural elevation differences on lake spillways and irrigation canals. Also turbines of small hydropower stations can be introduced as energy generators at elevation differences of the pipelines designed for pumping various types of liquid products. Additionally, the installation of small hydropower units is possible even at the technological water flows, such as industrial and sewage discharges. The natural conditions characteristic of Russia, especially of its European part, can ensure the production of electricity at damless hydropower plants, which fully meet the needs of the districts and are focused on the agricultural industry development. But it should be emphasized that for the active development of small hydropower plants, it is necessary to enshrine in law the standards for their construction and operation in the Russian Federation, as well as to develop government programs for mass private capital attraction in the projects for the construction of small hydropower plants.

As indicated in the study according to official statistics, 35% of gas is consumed for the operation of TPPs, which makes 45.1% of the electricity generation in the Russian Federation. Assuming that the total demand for electricity is unchanged, with the decrease in the proportion of electricity generated by gas-fired TPP by 13.9 p.p., the required amount of gas that is used to generate energy will decrease by 31.4%. On the basis of this logic, reduction in electricity generation by the coal-fired TPPs by 6.4 p.p. will decrease the need for coal by 36.6%.

Most modern studies on reducing energy intensity of the economy are more focused on the development of alternative energy (Özkale et al., 2017; Tarasova, 2018). But at the current stage of reducing the energy intensity of Russia's GDP this approach is economically unprofitable due to the high labor intensity and operating costs, which requires a long period of implementation. In view of this, it is advisable to provide development only at the level of certain enterprises. But subject to a significant reduction in energy intensity of the economy, this factor should be one of the determining factors in ensuring energy efficiency.

Also the economic structure optimization by reducing the proportion of energy-intensive industries is a common viewpoint of scientists regarding the energy intensity reduction in the Russian economy (Popescu, 2015). But this trend is also accompanied by a long period of implementation. And due to the fact that the potential of the Russian economic revival is actually exhausted, as well as the associated potential of transformational bonuses, this trend seems difficult to implement in practice (Yasin, 2018).

A distinctive feature of the approach to reducing the energy intensity of the Russian economy proposed in this study is that it is based on the actual capacities of the FEC of the Russian Federation and provides energy efficiency in the short term. The practical implementation of the proposed strategy of change for all items of the actual electricity generation in Russia can ensure a decrease in GDP energy intensity by 19.1%, provided that the rate of industrial energy consumption remains unchanged.

Undoubtedly, this optimization strategy for energy efficiency should be accompanied and supported by a system of practical measures aimed at increasing technological and operational discipline at the generating companies, which contributes to leveling overspending of energy resources and losses from mismanagement; creating an economic mechanism that would make consumers interested in rational use of fuel and energy and economical spending, both in the sectors of material production and in the non-material sphere; developing state investment programs and active attraction of private capital for the renewal of the energy and fuel consumption equipment to eliminate the wear of fixed assets in the energy industry. The whole cycle of energy conversion is subject to modernization – starting from the processes of fuel igniting and increasing the efficiency of the boiler units to the energy carrier transport system and its use by the end user; the introduction of advanced technologies in accordance with global trends, ensuring a decline in the share of energy consumption, which in turn will provide increase in the competitiveness of Russian products; at the state level, the application of energy-wasteful technologies should be banned, which is possible by means of extending the scope regulation of legislation on technical requirements for energy efficiency (requirements for specific consumption of energy resources, machinery, equipment, heat loss in buildings and water consumption in water treatment plants); introduction of tagging for energy-consuming equipment and machinery according to energy efficiency classes, establishing the obligatory nature of such tagging; economic incentives for improving utilization effectiveness of gas and other energy resources in the domestic market.

For example, this may be a call for government procurement auction to obtain goods corresponding to the best performance indicators in energy efficiency or subsidies for the development of mechanical engineering industry to create energy-saving prototypes of new generation. At the first stages of the development of this kind of production, the state should ensure the purchase of new equipment; public provision for utilization of the mechanism for the off-the-meter use of energy resources by equipping energy consumption metering devices in the consumer retail market, first of all this concerns residential consumers; development of automated systems for commercial utility metering in the retail market; provision of state support for the development and final formation of the institute of operators for commercial energy metering in the country; the implementation of special measures to improve energy efficiency of housing and communal services, as well as the introduction of the tariff method of return on investment capital; adaptation of concession contracts for transfer of housing and communal services to the management and the introduction of new standards and rules for efficient use of energy; incentives for enterprises developing and using alternative energy in economic activities to meet their energy needs, etc.

It should be emphasized that the research did not consider issues of energy conservation in the framework of the efficient consumption of Russian oil resources in the structure of the thermal power complex. It should be noted that this optimization factor of the energy efficiency strategy requires long-term implementation, since it is based on structural shifts of the Russian economy, as noted in the study. In view of this, in our opinion, this area of research in the field of energy saving and energy efficiency deserves a separate detailed study. But provided that the proposed optimization structure of the electricity generation creates prerequisites for a significant reduction in Russia's GDP energy intensity, this, in turn, will determine the increase in competitiveness and investment attractiveness of the country's industry. In other words, a theoretical basis is being formed for the development of new scientific concepts regarding the reduction in energy intensity of the Russian economy owing to its structural changes and an increase in the share of alternative energy sources in the structure of electricity generation.

5. CONCLUSION

Based on the developed optimization model of electric power generation structure in the Russian Federation to decrease energy intensity of the economy in the short term, the following conclusions can be drawn.

1. The Russian economy is characterized by a high level of energy intensity, the main causative factors of which are climatic conditions, the large scale of the territory and the energy-consuming structure of industry. In the absence of immediate prospects for structural changes in the Russian economy, the optimization of the electric power generation structure seems to be an effective way to reduce energy intensity of the economy in Russia, as a risk factor of economic and environmental security. This vision is determined by the fact that the optimization of the electric power generation structure will ensure a reduction in the operating costs of electricity generation. Therefore, it will reduce the consumption of gas and coal used by TPPs to produce electricity.
2. The developed optimization model of the electric power generation structure in the Russian Federation led to the conclusion that within the strategy implementation framework the following proportions of electricity generation should be provided for an efficient electric power generation structure: Nuclear power plants should produce 13.4% (consumption should decrease by 5.5%); natural gas fired thermal power plants generating 31.2% (consumption should decrease by 13.9%); coal-fired power plants producing 11.1% (consumption should decrease by 6.4%), and the share of hydropower plants should be 44.3% (consumption should increase by 26.9%). Introduction of an optimization electric power structure in Russia will ensure a reduction in the level of gas consumption for energy generation by 31.4%, the need for coal will decrease by 36.6%. In general, taking into account changes in all items of the electricity generation, the GDP energy intensity can be reduced by 19.1%, provided that the rate of energy consumption by industry remains unchanged.
3. The developed optimization measures for reducing energy intensity of the Russian economy are based on solving the problems of technological, organizational and regulatory nature of energy consumption and energy saving. Their practical implementation will contribute to the modernization of the energy sector funds, the introduction of advanced technologies and incentive norms and standards for the efficient use of energy resources in the domestic market of Russia. Such an approach will ensure the achievement of the optimal energy intensity of the Russian economy, which in turn will lead to an increase in the competitiveness of industry and a steady growth rate of the country's economic development.

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