Energy efficiency forecast of the Krasnoyarsk region

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Abstract. The energy efficiency of the Russian economy lags far behind the developed countries of the world. Increasing energy efficiency and, above all, energy saving, is the source that can provide additional economic growth through organizational and technical measures. The object of research is the economy of the Krasnoyarsk Territory, the increase in energy efficiency of which is of particular relevance due to its high energy intensity. The purpose of the study is to carry out an energy-economic analysis of the Krasnoyarsk Territory and to fulfill the forecast of the growth of the energy efficiency of the economy. The methodical approach developed by the authors is based on balance and statistical methods. In the course of the study, retrospective fuel and energy balances (FEB) of the Krasnoyarsk Territory (for the period 2005-2017) were developed, energy efficiency indicators were calculated and a regression equation was compiled for the forecast of the energy intensity of the gross regional product (GRP). The forecast for the development of the economy and the fuel and energy complex (FEC) of the Krasnoyarsk Territory has been made, the forecast TEBs have been developed (for the period up to 2050), the energy intensity of the regional GRP has been calculated for the long term, and measures have been proposed to increase energy efficiency.
Introduction

The main indicator that gives an idea of the state of energy efficiency of a particular country or its regions is the energy intensity of gross domestic / regional product (GDP / GRP). The energy intensity of Russia's GDP significantly exceeds this indicator in the countries with the most developed economies, for example, the USA - 1.6 times, Japan - 2.2 times, Switzerland - 3.7 times. This leads to the fact that the production of products with high energy consumption consumes more material, labor and financial resources. The increased specific consumption of fuel and energy resources (FER) during production leads to environmental degradation, increased rates of development of fuel deposits and their accelerated depletion, which will have a negative impact on future generations of Russians. Therefore, the growth of energy efficiency in the country and its regions is one of the most important priorities of the state energy policy and socio-economic development.

In the Krasnoyarsk Territory, the energy intensity of GRP is 1.5–2 times higher than the national average, which makes it necessary to develop special methods and models for studying the development processes of their fuel and energy complex in order to optimize the use of energy.

To solve the problem of improving energy efficiency, various methods and approaches are used that have shown their scientific and practical viability [1-20], however each specific region has its own characteristics, which can be taken into account with an individual approach. In addition, there are a number of tasks regarding the modeling of the influence of various factors on the energy intensity of GRP, the problem of forecasting the energy intensity of GRP depending on the dynamics of production indicators of the fuel and energy complex and the development of the regional economy remains poorly studied.

All this predetermined the relevance of the study aimed at identifying the degree of influence of the performance indicators of the fuel and energy complex on the energy intensity of the GRP of the Krasnoyarsk Territory.

Relevance of the problem

Krasnoyarsk Territory is one of the largest regions of Russia. Its area is 2366.8 thousand km² (13.8% of the entire country). The territory of the region extends from the shores of the Arctic Ocean to the mountainous regions of Southern
Siberia over 3000 kilometers, at the widest point the distance between the extreme points reaches 1,250 kilometers. The population of the Krasnoyarsk Territory is about 2.9 million people (2% of the population of Russia). The share of Krasnoyarsk Krai in the production of the GRP of Russia is 2.6%, in the volume of industrial production - 2.9%, the average per capita cash income of the region is 89.3% of the national average.

The economy of the Krasnoyarsk Territory is focused on: capital-intensive, energy-intensive production, based on the use of rich natural resources; for the production of intermediate products intended for deliveries to other regions of Russia and for export to the countries of near and far abroad.

The share of products of the fuel and energy sector of the region in the total industrial output in 2017 was 35%. At the same time, the main share (more than 90%) is taken by the extraction of oil, natural gas and coal.

The state of energy efficiency indicators of the Krasnoyarsk Territory is worse than the average in Russia, which depends both on objective factors (colder and longer winters, high-energy-intensive industry specialization, low population density), and technological lag in a number of industries (primarily in the energy sector), this is confirmed by higher specific fuel consumption for the production of energy in the region.

The importance of the problem of increasing energy efficiency in the Krasnoyarsk Territory has been recognized by the regional Government, as a result of which the state program of the Krasnoyarsk Territory «Energy Efficiency and Energy Development» was adopted, the purpose of which is to develop the energy industry at a fast pace for sustainable socio-economic development of the Krasnoyarsk Territory. One of the main objectives of the program is to increase the efficiency of energy supply and energy consumption in the Krasnoyarsk Territory, as a result, the energy intensity of the GRP is to decrease by 2030 by 16.6% compared with 2017. The implementation of the program’s activities will significantly increase the energy efficiency of the region and improve the quality of life of the population the edges.

**Formulation of the problem**

As part of the study, the task was set: to carry out an energy-economic analysis of the economy of the Krasnoyarsk Territory using the available retrospective data, on its basis to determine the impact of FEC performance
indicators on the growth of the region's energy efficiency. To conduct a comprehensive energy analysis of the economy of the Krasnoyarsk Territory, it is necessary to develop fuel and energy balances for the period 2005-2017. The research task is to build correlation-regressive dependencies of the main indicator of energy efficiency in the regional economy - energy intensity of GRP on the dynamics of gross consumption of fuel and energy resources, to develop a long-term forecast of energy efficiency improvement in the Krasnoyarsk Territory.

**Theoretical part**

The authors developed a methodical approach to energy-economic analysis and assessment of the energy-economic efficiency of the region based on the fuel and energy balance [19, 20]. This approach develops research by Russian and international scientists in this subject area [1-18], since it takes into account both the regional specifics and the investment policy of the region, and the state energy policy pursued by the Government of the Russian Federation. The research uses the information-computing complex created by the authors, consisting of an information reference system and a system of models: single-product balances of certain types of fuel and energy resources, summary fuel and energy balances, energy-economic analysis and statistical analysis of factors affecting the energy efficiency of the region's economy. The information reference system is used to provide the researcher with access to information. The form of information is set by the user for the convenience of its analysis. In this study, the effect of growth in the production indicators of the fuel and energy complex on the energy intensity of the GRP of the Krasnoyarsk Territory is determined.

**Results of research**

The energy efficiency analysis of the use of fuel and energy resources in the Krasnoyarsk Territory was made on the basis of the fuel and energy balance (Figure 1, Tables 1, 2).
Figure 1. Scheme of energy flows in the Krasnoyarsk Territory in 2017.

To perform an energy-economic analysis, retrospective fuel and energy balances of the Krasnoyarsk Territory for 2005-2017 (table 1) were developed.

Production of primary fuel and energy resources for the period 2005-2017 increased 2.2 times (mainly due to the production of hydrocarbons), export of energy resources - 3.6 times. A negative fact is the increase in total losses of fuel and energy resources by 3.8 times (mainly due to losses in the oil and gas industry). We also note the deterioration of energy efficiency in the Krasnoyarsk Territory compared with the average Russian indicators (table 2).

Table 1. The fuel and energy balance of the Krasnoyarsk Territory*, million tons of coal equivalent (tce).

| Year | Production of primary fuel and energy resources | Import of fuel and energy resources | Removal of fuel and energy | Electricity and heat production | Fuel consumption for the production of electricity and heat | Total loss of fuel and energy | Final consumption of fuel and energy resources |
|------|-----------------------------------------------|------------------------------------|---------------------------|--------------------------------|----------------------------------------------------------|-----------------------------|-----------------------------------------------|
| 2005 | 29.8                                          | 8.2                                | -11.3                     | 13.7                           | -21.7                                                    | -1.2                        | 17.5                                          |
| 2006 | 31.2                                          | 8.8                                | -12.4                     | 14.2                           | -22.4                                                    | -1.5                        | 18.0                                          |
| 2007 | 30.8                                          | 10.2                               | -13.8                     | 14.0                           | -22.0                                                    | -1.3                        | 17.9                                          |
| 2008 | 35.9                                          | 10.9                               | -18.9                     | 14.5                           | -22.6                                                    | -1.57                       | 18.3                                          |
| 2009 | 45.4                                          | 11.0                               | -29.2                     | 14.3                           | -22.2                                                    | -1.4                        | 17.8                                          |
| 2010 | 46.9                                          | 10.5                               | -29.3                     | 14.6                           | -22.5                                                    | -1.7                        | 18.5                                          |
| 2011 | 49.5                                          | 10.0                               | -31.0                     | 13.7                           | -21.1                                                    | -1.6                        | 19.5                                          |
| 2012 | 57.8                                          | 9.1                                | -36.5                     | 13.7                           | -21.1                                                    | -5.0                        | 18.0                                          |
| 2013 | 59.2                                          | 9.3                                | -37.2                     | 13.8                           | -21.0                                                    | -6.0                        | 18.1                                          |
| 2014 | 58.7                                          | 4.5                                | -31.6                     | 14.2                           | -21.3                                                    | -5.6                        | 18.9                                          |
Table 2. The main indicators of energy efficiency.

| Indicator                                      | Krasnoyarsk region | Russia   |
|-----------------------------------------------|--------------------|----------|
|                                               | 2005   | 2010   | 2015   | 2016   | 2017   | 2017   |
| GRP in 2017 prices *, billion rubles          | 130    | 157    | 179    | 182    | 188    | 74927  |
| Energy intensity of GRP**, kg of coal equivalent / thous. rub. | 20,4   | 17,8   | 17,2   | 16,6   | 16,0   | 10,9   |
| Electric intensity of GRP, kWh / thous. rub.  | 38,1   | 33,7   | 29,6   | 29,7   | 28,1   | 14,5   |
| Heat capacity of GRP, Gcal / rub.             | 39,0   | 30,8   | 24,2   | 24,9   | 23,0   | 17,0   |
| Specific fuel consumption per vacation:       |        |        |        |        |        |        |
| - electricity at thermal power plants, grams of coal equivalent / kWh | 334, 344, 354, 351, 340, 303,7 | 7       | 6       | 4       | 5       |
| - heat energy at thermal power plants, kg of coal equivalent / Gcal | 159, 162, 170, 171, 169, 156,6 | 9       | 3       | 4       | 6       |
| - тепловая энергия в котельных, kg of coal equivalent / Gcal | 193, 187, 189, 180, 178, 166,6 | 1       | 5       | 9       | 4       | 5       |

Note - * GRP in 2017 prices calculated according to Rosstat; ** the energy intensity of the GRP is calculated by the gross consumption of primary FER; *** for comparison.
\[ Y_i = 17,639 + 0.625X_i - 0.011X_2, \]  
(1)

where \( Y_i \) – Energy intensity of GRP, kg of coal equivalent / thous. rub.;  
\( X_i \) – gross consumption of primary fuel and energy resources, million tons of coal equivalent;  
\( X_2 \) – GRP in 2017 prices, billion rubles.

The correlation coefficient of equation (1) - 0.995 denotes a significant statistical relationship between variables and the energy intensity of GRP. The statistical reliability of the obtained equation (1) is estimated by the level of significance of the Fisher criterion, where \( p=1.4*10^{-10} <0.05 \), which confirms the good adequacy of the energy-intensity relation between the GRP of the Krasnoyarsk Territory and the explanatory variables.

Using equation (1), the forecast of the energy intensity of the GRP of the Krasnoyarsk Territory in 2020–2050 was made. For this, a forecast of the development of the economy and the fuel and energy complex of the Krasnoyarsk Territory was made. Scenario 1 corresponds to the lower limit of moderate development of the economy and the fuel and energy complex, and scenario 2 corresponds to a more optimistic development (table 3). Energy consumption growth over the period 2020-2030 calculated using models of fuel and energy balance. According to the forecast, in scenario 1, the average annual growth rate of gross consumption of fuel and energy resources for the period 2017-2050, will be 1.2%, in scenario 2 - 1.5%. The average annual growth rate of GRP in Scenario 1 is 1.5%, in Scenario 2 it is 2%.

The decrease in the energy intensity of the GRP of the Krasnoyarsk Territory in 2050 compared with 2017 in scenario 1 will be 40%, in scenario 2 - 84% (table 3).

The growth of energy efficiency in the economy of the Krasnoyarsk Territory depends on the implementation of energy-saving measures in all areas of economic activity, which will reduce the cost of production and consumption of energy resources, reduce their losses, achieve planned indicators of socio-economic development with less energy and financial costs.

**Table 3.** Forecast of energy intensity of the GRP of the Krasnoyarsk region.

| Year | Gross consumption of primary fuel and energy, million tce | GRP in 2017 prices, billion rubles | Energy intensity of GRP*, kg of coal equivalent / thous. rub. |
|------|----------------------------------------------------------|-----------------------------------|-------------------------------------------------------------|
|      | Scenario 1 | Scenario 2 | Scenario 1 | Scenario 2 | Scenario 1 | Scenario 2 |
| 2017 | 30,1       | 1882,0     | 16,0       | 2          | 2          |

7
| Year | Growth Rate | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth | Growth |
|------|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| 2020 | +31.2       | +31.5  | +1968.3| +1997.5| +15.5  | +15.4  |
| 2025 | +33.0       | +33.9  | +2120.4| +2205.4| +15.0  | +14.6  |
| 2030 | +35.0       | +36.5  | +2284.3| +2483.7| +14.4  | +13.2  |
| 2035 | +37.0       | +39.4  | +2460.8| +2688.4| +13.8  | +12.7  |
| 2040 | +39.2       | +42.4  | +2651.0| +2968.2| +13.1  | +11.6  |
| 2045 | +41.6       | +45.7  | +2855.9| +3277.2| +12.3  | +10.2  |
| 2050 | +44.0       | +49.2  | +3076.6| +3618.2| +11.4  | +8.7   |

Growth (+), Decrease (-)

Note - * in 2017 prices; Scenario 1 - the lower limit of the moderate development of the economy and the fuel and energy complex; Scenario 2 - the upper limit of moderate economic development and fuel and energy.

Conclusion

In the course of the study, retrospective fuel and energy balances for 2005–2017 were developed, and an energy-economic analysis was carried out on their basis. The existing problems in the fuel and energy complex of the Krasnoyarsk Territory are revealed: high specific fuel consumption for the production of electrical and thermal energy in thermal power plants and boiler rooms compared to the average Russian indicators; growth of total losses of fuel and energy resources in the oil and gas industry; the large dependence of electricity generation on hydropower, all this affects the energy intensity of the region's GRP.

Using the least squares method, a multiple regression equation has been developed for the energy intensity of the GRP of the Krasnoyarsk Territory depending on the gross consumption of fuel and energy resources. With the help of the multiple regression equation, the forecast reduction of the energy intensity of the GRP was made. The forecast of the development of the economy and the fuel and energy complex of the Krasnoyarsk Territory was preliminarily made. For the period 2017-2050 the energy intensity of the GRP can decrease 1.4-1.84 times, depending on the growth rate of the economy and the fuel and energy complex.

The results can be used to predict changes in the energy intensity of the GRP, depending on the development of the economy and the fuel and energy complex of the region. The executive authorities of the region using the
The proposed model can receive information about the planned change in the main indicator of energy efficiency - energy intensity of GRP in the region.

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