The growth of energy efficiency of the Baikal region is the basis for its sustainable development

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Abstract. The Baikal region has a special status of economic activity, as an object of world heritage. In Lake Baikal there are about 20% of the world's reserves of fresh fresh water. The urgency of energy efficiency growth is determined by the industry specialization of the economy and the requirements for preserving the Baikal nature. The purpose of the research: to identify the significant factors affecting the energy efficiency of the economy and to propose mechanisms for their implementation. A methodical approach is developed based on methods of economic-mathematical modeling, system analysis, statistical analysis, balance and indicative methods. An information and computing complex has been developed that includes: a system of models and databases for analyzing and forecasting the development of the fuel and energy complex of the eastern regions of Russia; economic-mathematical models of fuel and energy balances; methods for assessing the energy efficiency of the economy; methods of statistical analysis to identify factors that affect energy efficiency. Significant factors of reducing the energy intensity of the gross regional product of the Baikal region have been identified, and multiple regression equations have been developed to predict the energy intensity.

1. Introduction

The Baikal region (BR) is a unique natural territory of world importance, which includes three subjects of the Russian Federation (RF), united by economic and geographical affiliation to the Baikal Lake basin, such as the Irkutsk Region, the Republic of Buryatia and the Trans-Baikal Territory. BR has an advantageous geographical location with direct access to the borders of Mongolia and China, which creates favorable conditions for mutually beneficial international economic cooperation. Within the boundaries of the Baikal natural territory a special regime of economic activity is established, which contributes to the preservation of the unique lake. The area of the BR occupies a huge territory - 1558.1 thousand km², exceeding the territories of France, Spain and Germany combined, however, the population density in the region is very low - 2.9 people / km², which causes a number of problems, including the efficiency of energy and fuel supply to consumers in the region.

An important condition for ensuring the sustainability of the BR economy is a reliable, efficient and environmentally friendly energy supply to consumers. The economy of BR is highly energy-intensive because of its industry specialization and cold climate, this leads to increased costs of fuel and energy resources. The need for fuel and energy is provided by the fuel and energy complex, it consists of enterprises of electricity, heat power, oil, gas and coal industries. The potential of the fuel and energy sector of the BR is great and can meet the needs of its own economy and exports, however,
modern realities require more efficient use of fuel and energy resources in all spheres of economic activity.

In modern conditions, when the country's economy is burdened by anti-Russian sanctions, the need to increase its energy and environmental efficiency is increasing both as a means of saving material and financial resources and as an incentive for modernizing production processes in the fuel and energy complex of the Russian Federation at a higher technological level.

Improving energy efficiency is one of the main priorities of the state economic policy, allowing to provide increasing volumes of energy consumption with the same volumes of FER production or with their insignificant growth. The Government of the Russian Federation adopted a number of directive documents in the fuel and energy complex, which legislatively fix quantitative and qualitative indicators of energy efficiency. The purpose of the current State Program of the Russian Federation "Energy Efficiency and Energy Development" is reliable provision of the country with fuel and energy resources, increasing the efficiency of their use and reducing the anthropogenic impact of the fuel and energy complex on the environment. To monitor the implementation of directive indicators of energy efficiency, fuel and energy balances are developed, which shows the movement of fuel and energy resources from their production to final consumption. Complex energy-economic analysis based on the fuel and energy balance is of great practical importance. It allows to determine the size of fuel and energy consumption, assess the effectiveness of their use in each type of economic activity and the economy as a whole, determine the volume of energy losses, assess the potential for energy conservation, and outline priority measures to improve the situation.

The development of optimal forecast fuel and energy balances that allow more efficient use of energy resources is one of the mechanisms for implementing the state energy policy. This information is necessary for the executive authorities. It allows to optimize state regulation in the sphere of fuel and energy complex and make the most reasonable management decisions.

2. Methodology
The study of energy saving and energy efficiency in Russia on the basis of the fuel and energy balance in the conditions of a centralized economy was initiated in the 1920s and 1930s (Kzhizhanovskii G M, Veits V I, Rusakovskii E A, 1932; Probst A E, 1937), continued in the 1950-1980s (Melentiev L A, Styrikovich M A, Steinhaus E O, 1962; Nekrasov A S, Sinyak Yu.V., Yangropolsky V A, 1974; Makarov A A, Vidorchik A G, 1979). In subsequent years, studies in this subject area in the new economic conditions have been developed by many Russian scientists (Bashmakov I A, 2007; Bushuyev V V, Troitsky A A, 2004; Galieva T M, Masterpanov A M, 2003; Gasho E G, Repetskaya E V, Bandurist V N, 2010; Churashev V N, Suslov N I, Markova V M, Chernova G V, 2010; Chupyatov V V, Makarov A A, Medvedeva E A, 2001; Filippov S P, 2005).

In addition to domestic sources, the authors turned to publications of foreign authors, whose sphere of interests are the issues of optimal use of energy resources and analysis of energy efficiency (Rosenfeld A H, 1999; 2009; Patterson M, 1996; Haas R, 1997; Hotelling H, 1931; Solow R M, 1974, Nordhaus William, 1979; Chandler Morse, 1973; Lakshmanan, Ratick Sam, 1980; Herring Horace, Sorrel Steve, 2009).

To solve the problem of increasing energy efficiency, different methods and approaches are used. They showed their scientific and practical significance at certain stages of economic development for individual countries and regions. However, the constantly changing conditions of development and regional features of the economy do not allow us to create a universal method. In particular, each region of Russia has its own specifics, accounting for which is possible only with an individual approach to forecasting the development of the region's fuel and energy complex and improving the energy efficiency of its economy. There are a number of unresolved issues in modeling the influence of various factors on the energy intensity of the gross regional product of Russia's regions under the conditions of economic sanctions, especially those affecting the fuel and energy complex.

The authors develop the research of Russian and foreign scientists. Their methodical approach to the assessment of energy efficiency, taking into account the investment component and the latest
directive documents of the Government of the Russian Federation in the field of energy, is based on the principles of system analysis, methods of economic and mathematical modeling and methods of balance.

The novelty of the research is that in order to assess the energy efficiency of the Baikal region, a multitude of mutually complementary scientific methods of cognition are used, with the help of which, and taking into account the forecasts of the development of the country's economy and the fuel and energy complex of Russia, factors and directions of growth in the energy efficiency of the regional economy are determined and long-term development of the fuel and energy sector in the Baikal region.

The research tool is an information and computing complex for the formation of fuel and energy balances of the subjects of the Russian Federation in the territory of Siberia and the Far East (ICC "Fuel and energy balances of Siberia and the Far East") (Muzychuk S Y, Muzychuk R I, 2018), which consists of two interrelated components: an information and reference system and a system of models. The information and reference system (IRS) provides an interface to access data in a form convenient for analysis and is used to improve the effectiveness of the research process. The system of models includes economic and mathematical models: single-product balances of certain types of fuel and energy resources, summary fuel and energy balances, and economic analysis (Figure 1).

**Figure 1.** The scheme for modeling the development processes of the Fuel and energy complex in the Baikal region.

Analysis of the current state of the fuel and energy complex of the regions allows improving the quality of forecasts and forming more rational fuel and energy balances. For the compilation of retrospective balances, the annual statistical reports on production, consumption, export, import, state of reserves and energy losses developed by Rosstat are used, reliable Internet sources that are publicly.

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available. If necessary, the reporting of energy enterprises is requested. Regional single-product balances of certain types of fuel and energy resources (coal, gas, oil, electric power, heat energy, etc.) are developed in natural units, which, with the help of caloric equivalents, are converted into units of conventional fuel and combined into fuel and energy balances of regions (subjects of the Russian Federation) and the macroregion (BR). Energy-economic analysis is in progress. The cost estimates are calculated, the total costs for the energy supply to consumers are determined. The main energy efficiency indicators are calculated: electric capacitance of the gross regional product (GRP), heat capacitance of the GRP, energy intensity of the GRP, unit costs of fuel and energy resources in the energy sector, the coefficients of their useful use, energy losses in production and consumption. Systemic energy-economic analysis makes it possible to identify the main problems in the fuel and energy complex of the regions.

The equations of multiple regression of energy intensity of GRP, of electric capacitance of GRP and heat capacitance of GRP are developed, the factors influencing the energy efficiency of the Baikal region's economy are revealed, their assessment is given, energy saving measures and perfection of the fuel and energy balance structure are proposed, which will allow to create more rational forecast fuel and energy balances. With the help of statistical methods, an integrated forecast of energy efficiency indicators is carried out, where certain parameters of indicators are specified for calculation. To obtain the most detailed forecast, it is necessary to use the entire system of models (see Figure 1).

The initial information in the development of a detailed forecast for the development of the fuel and energy complex of the Baikal region is information from optimization and imitation models of a higher hierarchical level (fuel and energy complex of the country, social and economic development of the country and regions, external links of regions, etc.) (Saneyev BG, Agafonov GV, Bandman MK ..., 2003). If the predictive models are not balanced, feedbacks come into play, and multiple iterations provide the right solution.

3. **Assessment of energy efficiency of the Baikal region**

The large area of the BR (1558.1 thousand km², 9.1% of the territory of the Russian Federation) is inhabited only slightly, the population as of 01.01.2016 was 4478 thousand people (3.1% of the total Russian population). In 2016, the share of BR in the country's GRP, in the production of industrial products, in fixed assets of the economy amounted to 2.2%, in all-Russian investments - 2.6%. In 2016, in the structure of the region's industrial output, the share of the fuel and energy sector was 49.7%.

One of the conditions for the transition to sustainable social and economic development of the BR is the growth of energy efficiency. An important role in solving this problem is given to the fuel and energy complex of the BR, which makes a significant contribution to the country's production performance. In 2016, the enterprises of the fuel and energy complex of the BR produced 9.5% of Russian coal, produced 5.8% of electricity, processed 3.4% of crude oil, and extracted 3.4% of Russian oil. The fuel and energy complex of the BR basically provides the need for its own economy in the energy resources, its share in 2016 accounted for 12.5% of the coal consumed in the country, 5.8% of electricity, 4.2 thermal energy, 3.0% of oil products.

The development of the fuel and energy complex of the BR in recent years is affected by the crisis in the economy (reduced demand for fuel and energy resources), therefore, there has been a decline in performance in electricity, heat and coal production, but in oil production there is a trend of stable and dynamic growth, due to this in 2010-2016 the production of primary energy resources increased by 78%, the export of fuel and energy from the BR increased by 84.5% (Table 1).
Table 1. The aggregated fuel and energy balance of the Baikal region (2010-2016), million tons of fuel equivalent.

| Year | Production of primary fuel and energy resources | Import of fuel and energy resources | Export of fuel and energy resources | Production of energy carriers | Consumption of fuel and energy resources for the production of energy carriers | Loss of fuel and energy resources in the process of transformation and transmission | Final fuel consumption | Final consumption of energy carriers |
|------|-----------------------------------------------|-----------------------------------|-----------------------------------|-------------------------------|-------------------------------------------------------------|--------------------------------------------------------------------------------|----------------------|----------------------------------|
| 2010 | 31.5                                         | 18.7                              | -24.5                             | 17.3                          | -22.9                                                        | -2.3                                                             | -3.4                | -14.5                                           |
| 2011 | 39.3                                         | 18.5                              | -31.9                             | 16.7                          | -22.1                                                        | -2.6                                                             | -3.4                | -14.5                                           |
| 2012 | 46.7                                         | 19.4                              | -39.3                             | 17.3                          | -22.9                                                        | -3.4                                                             | -3.6                | -14.3                                           |
| 2013 | 46.3                                         | 20.0                              | -39.7                             | 15.9                          | -21.1                                                        | -3.8                                                             | -3.6                | -14.1                                           |
| 2014 | 48.6                                         | 18.6                              | -40.4                             | 16.0                          | -21.1                                                        | -3.8                                                             | -3.7                | -14.1                                           |
| 2015 | 52.8                                         | 16.9                              | -43.2                             | 15.1                          | -20.0                                                        | -4.0                                                             | -3.8                | -13.9                                           |
| 2016 | 56.1                                         | 16.7                              | -45.2                             | 15.4                          | -20.2                                                        | -4.7                                                             | -3.9                | -14.2                                           |

Source: authors’ estimates

The decline in industrial production and a reduction in the demand for energy carriers led to a decrease in their output by 11% by 2016. The main fuel in the production of energy in the BR is coal, whose share in 2016 was 84%, this significantly complicates the environmental situation in the BR (of the 20 Russian cities with the highest level of atmospheric pollution, nine are located in the BR). Emissions of harmful substances per capita in the BR are 34% higher than the average for Russia, and in large industrial centers - 1.5-2 times. This is a problem that needs to be solved as soon as possible, the growth of energy production based on the use of gas and renewable energy sources (RES) can become one of the effective ways to solve it.

Negative factor in the BR is the growth of energy losses during their transformation and transmission - 2 times in 2010-2016. (due to the growth of oil production, the volume of flaring of associated petroleum gas in flaring facilities has increased).

On the basis of the fuel and energy balance, the energy efficiency indicators of the BR were calculated. For the period 2010-2016, energy intensity GRP BR (in comparable prices in 2010) decreased by 9.4%, GRP electric capacity - by 24.8%, heat capacity of GRP - by 23.9% (Table 2).

The energy efficiency growth in BR reflects the impact of the following processes:
- structural changes aimed at increasing the share of low energy-intensive types of economic activities in the GRP volume;
- implementation of energy conservation programs in the region.

4. Statistical analysis, identification of factors affecting the energy efficiency of the Baikal region

Correlation-regression analysis was used to determine the strength and direction of the relationship between the energy efficiency values and the fuel-energy balance articles.

As a result of several iterations, in order to obtain adequate criteria, the multiple regression equation for the GRP energy capacity was obtained:

\[ Y_1 = -10,504 + 2,316 \cdot X_1 - 0,023 \cdot X_2, \]  

\( Y_1 \) - GRP energy intensity;
\( X_1 \) - gross consumption of primary fuel and energy resources;
\( X_2 \) - GRP in comparable prices in 2016.
### Table 2. Main indicators of energy efficiency of the Baikal region.

| Indicator                                                                 | 2010    | 2011    | 2012    | 2013    | 2014    | 2015    | 2016    | RF** 2016 |
|--------------------------------------------------------------------------|---------|---------|---------|---------|---------|---------|---------|----------|
| GRP in 2010 prices, bln. Rub. Consumption:                                |         |         |         |         |         |         |         |          |
| - primary fuel and energy resources, mln tons of fuel equivalent.         | 25,8    | 25,9    | 26,9    | 26,6    | 26,8    | 26,5    | 27,6    | 842,5    |
| - Electricity, billion kWh ⋅ h                                           | 67,3    | 70,1    | 71,0    | 70,0    | 69,5    | 66,2    | 62,8    | 1091,0   |
| - heat energy, mln Gcal                                                  | 57,1    | 54,8    | 56,8    | 54,1    | 52,8    | 52,3    | 53,6    | 1283,5   |
| Energy intensity of GRP *, kg of equivalent fuel/thousand. rub.          | 30,4    | 29,1    | 28,4    | 27,8    | 27,5    | 27,1    |         | 19,9     |
| Electric capacity of GRP, kW ⋅ h / th. rub.                             | 79,5    | 78,8    | 74,9    | 73,1    | 71,3    | 67,9    | 63,7    | 25,7     |
| Heat capacity of GRP, Gcal / rub.                                       | 67,4    | 61,7    | 60,0    | 56,5    | 54,2    | 53,6    | 54,4    | 30,3     |
| Specific expenditure on leave:                                          |         |         |         |         |         |         |         |          |
| - electricity from TPP, gram of conventional fuel /KWh.h.               | 347,6   | 348,5   | 348,9   | 345,9   | 344,1   | 344,8   | 342,7   | 314,2    |
| - Thermal power from TPP, kg of equivalent fuel / Gcal                  | 158,1   | 154,9   | 150,4   | 156,1   | 155,5   | 156,5   | 155,1   | 149,2    |
| - heat energy from boiler houses, kg of equivalent fuel / Gcal           | 193,3   | 188     | 191,6   | 197     | 193,5   | 191,2   | 204,3   | 159,6    |
| The coefficient of useful use of energy resources in the energy sector  | 75,5    | 75,6    | 75,5    | 75,4    | 75,8    | 75,5    | 76,2    |          |
| The coefficient of useful use of energy resources in final consumption  | 69,4    | 69,1    | 66,5    | 66,5    | 66,4    | 66,8    | 65,6    |          |
| Losses of electric power in the networks, billion kWh ⋅ h               | 5,9     | 5,1     | 5,9     | 5,6     | 6,0     | 5,9     | 6,4     | 107,2    |
| Same as% of consumption                                                 | 8,8     | 7,3     | 8,3     | 8,0     | 8,6     | 8,9     | 9,5     | 9,9      |
| Heat losses in mains networks, mln Gcal                                  | 5,2     | 4,8     | 4,6     | 4,4     | 4,4     | 4,4     | 4,1     | 97,5     |
| Same as% of consumption                                                 | 9,1     | 8,8     | 8,1     | 8,1     | 8,3     | 8,4     | 8,4     | 8,1      |

**Notes:**
- * GRP energy consumption by gross consumption of primary fuel and energy resources;
- ** for comparison with RF.
Source: Rosstat data and authors’ calculations

The coefficient of multiple correlation of equation (1) showed the existence of a strong statistical relationship between the values of the expenditure items of the fuel and energy balance and the energy intensity of the GRP. Variation of the energy capacity by 98.7% is explained by the action of four factor variables and by 1.3% by the action of other unaccounted factors.

Let us compose the multiple regression equation for gross consumption of primary fuel and energy resources.

\[ X_1 = -1,283 + 1,222 \cdot X_3 + 1,130 \cdot X_4 + 1,036 \cdot X_5 + 0,915 \cdot X_6, \]  
\[ X_3 - \text{final fuel consumption}; \]
\( X_4 \) - final consumption of electricity;
\( X_5 \) - final consumption of heat energy;
\( X_6 \) - total losses of fuel and energy resources.

The adequacy check for equation (2) confirmed its high statistical significance (Table 3).

**Table 3.** Analysis of the equation of gross consumption of primary fuel and energy resources.

| R   | \( R^2 \) | Standard Error | Fisher test | \( X_4 \) | \( X_5 \) | \( X_6 \) |
|-----|-----------|----------------|-------------|----------|----------|----------|
| 0,997 | 0,994 | 0,05 | 511,461 | 5,766 | 8,805 | 16,338 | 15,611 |

Using the equations (1) and (2), the energy consumption of the GRP of the Baikal region for the period up to 2050 is predicted (Figure 2).

![Graph](image_url)

**Figure 2.** Actual value of the energy intensity of the GRP of the Baikal region and its calculated values using equations (1) and (2), in prices of 2016.

Thus, the most significant factors affecting the energy efficiency of the BR economy are:
- Reduction of the specific fuel consumption for the production of electricity and heat;
- Reduction of losses of fuel and energy resources during their extraction, processing, and transportation;
- Reduction of unit costs of fuel and energy resources for production, especially in the most energy-intensive types of economic activity (metallurgy, timber processing, petrochemicals, etc.);
- Reducing the consumption of energy resources in the budgetary sphere, in housing and communal services and among the population due to more rational consumption.

The mechanisms for implementing the energy efficiency enhancement factors of the BR economy are:
- in the energy sector: the introduction of energy-saving technologies, innovative equipment in production activities, as well as in the processes of transmission and distribution of fuel and energy resources, the fuller use of secondary energy resources;
- in non-energy spheres of economic activity: introduction of innovative technological processes that allow rationally reduce consumption of fuel and energy resources, as well as systematic implementation of resource-saving measures in accordance with regional energy saving programs.

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