The energy-efficient development of the Russian Federation entity: models and information technologies

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Abstract: In the article, the task of the energy-efficient development of the region is reduced to search for coordinated scenarios for the development of the regional economy and fuel and energy complex (FEC), in which the maximum approach to the objectives for a comprehensive system of indicators is achieved. This system of indicators contains: economic indicators characterizing the regional growth of human welfare and the potential of the regional economy, as well as energy indicators characterizing the efficiency of production processes, processing, transportation and the use of all types of fuel and energy resources in the region. The authors developed a dynamic multi-sector model of the fuel and energy complex as part of the economic model of the Russian Federation region and proposed the methodology that ensures approval and iterative coordination of scenario forecasts of energy consumption and production of energy resources in the region by main types of fuel and energy resources. To assess the achievement of the objectives of the energy-efficient development of the region of the Russian Federation, the authors developed methods and algorithms that make it possible to solve the tasks of multiobjective management of the regional economy and he fuel and energy complex for many dozen objectives and hundreds of control variables. Based on the methods and models presented in the article, information technology for forecasting and strategic planning is implemented in the form of the forecasting and analytical system designed to support management decisions of regional authorities in the tasks of increasing energy efficiency and energy security of the Russian Federation entity. The developed tools were calibrated on the statistical material of the Samara region.

Key-Words: energy-efficient development, energy indicators, modeling, forecasting, strategic planning

1 Introduction

Economic development must be energy-efficient. At present, this thesis is becoming increasingly relevant both in the European Union and in Russian regions. The European Energy Commission has defined the content and objectives of the energy-efficient development of the EU for 2020 and 2030 [1]. It is planned to increase energy efficiency at all stages of the energy chain, from generation to final consumption. At the same time, the benefits of energy efficiency should outweigh costs, therefore EU measures focus on sectors where savings potential is greatest, for example, to reduce the cost of heating and cooling residential and industrial buildings, which account for half of EU energy consumption. The Commission published guidelines on good EU practice in the field of energy efficiency [2]. This practice is mainly aimed at energy saving (energy-efficient renovation of buildings, reduction of energy intensity of products, installation of smart electricity and gas meters, launch of "energy-efficient" goods for the population) [3].

According to the Energy Strategy of Russia [4, 5], the energy-efficient development of the region means the development of a sustainable and self-regulating system for ensuring regional energy security, taking into account optimization of the territorial structure of production and consumption of fuel and energy resources (FER). Target energy indicators of the strategy include: reduction of unit costs for FER production, increase in production of basic energy resources, increase in primary energy exports, reduction of specific indicators of pollutant emissions into the atmosphere, reduction of greenhouse gas emissions, decrease in specific energy intensity and electrical capacity of gross domestic product, and others.

It is worth noting that the objectives for energy indicators may contradict the objectives of the regional economy as a whole, for example, the requirement to reduce energy intensity of GRP may contradict the decision to develop energy-intensive industries, or the export-oriented development may reduce energy security of the region. This fully applies to resource-producing and energy-producing regions of Russia, such as, for example, the Tyumen Region and the Krasnoyarsk Territory. In fact, the best energy-efficient indicators are achieved in the transition from energy-intensive industries to services, which is impossible for many Russian regions because of the existing structure of the Russian fuel and energy complex. Energy efficiency indicators are also heavily influenced by changes in energy prices, and these changes can be both effective for the regional economy as a whole and ineffective. Therefore, the objectives for the energy-efficient development of the subject of the Russian Federation should be balanced with the objectives of the regional social and economic development. That is, the energy-efficient development of the region must be linked to economic efficiency of its development and functioning. Researchers are still making great efforts to identify the correct relationships between indicators of general economic efficiency and efficiency of energy solutions [6, 7]. Efforts are also continuing to further expand the concept of efficiency of the regional fuel and energy complex, in particular the application of multi-objective (multicriteria) approaches, reflecting not only economic but also social demands of society for energy (for example, nuclear) [8].

In this regard, the task of the energy-efficient development of the region should be reduced to finding coordinated scenarios for the development of the regional economy and the fuel and energy complex, which maximize the objectives of the proposed system of economic indicators and energy indicators characterizing the development of the regional economy as effective. In the end, the economically effective development (the growth of GRP and human welfare) is consistent with the increase in production efficiency, conversion, distribution and final consumption of all types of fuel and energy resources.

To solve this problem, forecasting and analytical complexes and information technologies are needed that would allow regional authorities to carry out scientifically based forecasts of the consequences of management decisions made, to form balanced systems of the objectives for the energy-efficient development of the region and to assess their attainability.

The literature describes a large number of systems for supporting management decisions in the energy and economy sectors, from systems whose sphere of application is limited to management of individual energy carriers, to complex systems that view energy as an integral part of the economy [9, 10]. Existing systems for supporting management decisions in the energy sector are characterized by a wide variety of decision-making models, reviews, discussions and comparisons which are given in the articles written by Psarras, Capros and Samouilidis [11], Greening and Bernow [12], Becalli, Cellura and Mistetta [13]. In the article by Capros et al. [14] the authors explored theoretical and empirical problems that arose when creating systems of energy-economy models used for short-and medium-term forecasting (Hermes-Midas systems). The most important component of any system for supporting management decisions in the energy sector is the FEC model and its links with the rest of the economy. The article by Jebaraj and Iniyan [15] reviewed more than 250 energy models widely used in different countries to analyze and forecast the energy development. The optimization models that are analyzed, in particular: various types of models to optimize the fuel and energy balance; step models to optimize energy systems; models that minimize energy intensity of GDP, taking into account various constraints; planning models of energy supply and demand using a multicriteria programming methodology on Leontiev’s traditional model of "input-output". A special place in the literature on modeling is given to computable general equilibrium models (CGE) [16, 17]. Due to their ability to simulate the response of the system to external influences, these models are widely used to analyze the consequences of management decisions [18]. In the field of energy, CGE-models appeared as useful empirical tools, allowing estimating the scale of economic consequences of energy and environmental policy [19-21].

However, the most pragmatic interest for the authors was represented by Russian studies in the field of energy modeling and forecasting, since they take into account the features of national management institutions and the statistical description of modeling objects. At the moment, the most important one is the technology of energy modeling and forecasting, developed at the Energy Research Institute of the Russian Academy of Sciences (ERI RAS) [10]. This technology is successfully used for forecasting both the Russian and world energy [22]. The main feature of this technology is the formation of the consistent and mutually agreed system of forecasts of the country's economic development, consumption and production of key fuels and energy, and financing of certain fuel and energy sectors. Iterative coordination in the system of forecasts is made through energy and financial balances, formed for individual regions and for the country as a whole. This takes into account the production characteristics of the fuel and energy sector and interbranch balance sheets of the national economy.

The analysis of literature sources shows that there are currently no systems like those developed at the ERI RAS at the regional level. Some domestic developments on the formation of the regional fuel and energy balance, for example, [23, 24], do not fully correspond to the pressing needs of the regional development. In particular, they do not have the tools for forecasting the fuel and energy balance, the tasks of strategic goal-setting for the development of the fuel and energy sector are not being solved, which is especially important in connection with the adoption of the Federal Law on Strategic Planning (Federal Law No. 172-FZ of June 28, 2014).

The main objective of this study was the development of methods, models and information technologies to support management decisions of regional authorities in the tasks of increasing energy efficiency and energy security of the regional economy. To achieve this objective, the following tasks were set and solved:

- The development of the system of target indicators for the energy-efficient development of the regional economy (indicators of the growth of human welfare and the potential of the economy, as well as energy indicators characterizing the efficiency of production processes, conversion, distribution and final consumption of all types of fuel and energy resources);
- The development of the model for the regional fuel and energy sector as a dynamic multi-sectoral model in the model of the economy of the Russian Federation entity;
- The development of information technology that ensures reduction and iterative coordination of scenario forecasts of energy consumption and production of energy resources in the region by main types of FER;
- The development of tools to search for coordinated scenarios for the development of the fuel and energy sector and the regional economy, which maximize the objectives of the proposed system of indicators characterizing the development of the regional economy in terms of economic and energy efficiency.

The article is structured as follows. After introduction and goals of research there is a formal statement of the problem of the energy-efficient development of the region and a discussion of models and methods for solving this problem. The third section is devoted to reviewing the results that can be used by regional governments in their activities. The fourth section discusses the main problems of using the results obtained.

2. Methods

2.1. The formal statement of the problem

The task of the energy-efficient development of the region will be reduced to search for coordinated scenarios for the development of the regional economy and fuel and energy complex, whereby the chosen system of economic and energy indicators is maximized to the objectives that characterize the development of the regional economy as energy-efficient. The authors denote the general system of indicators of the regional development:

$$E = [E_{econ}, E_{ener}]^T, \tag{1}$$

where E_{econ} - the vector of indicators that characterizes the socio-economic development of the region, namely: the level of human welfare and the potential of the regional economy;

E_{ener} - the vector of energy indicators, characterizing the development of the regional economy in terms of energy efficiency.

The authors denote:

$$E^0(t) = [E^0_{econ}(t), E^0_{ener}(t)]^T \text{ -} \tag{2}$$

the vector of target values set for development indicators on the horizon of strategic planning $[0, t_T]$ at points $t = t_1, t_2, ...t_T$, and, the vector of target values for energy indicators $E^0(t)$ is the task plan for the energy-efficient development. Adding the vector $E^0_{ener}(t)$ to the general vector of regional objectives (2) gives the regional development an "energy efficient coloring".

Formally, the task of the energy-efficient development of the region (the subject of the Russian Federation) can be reduced to the following task of multi-criteria optimization:

$$\left\| E(U,t) - E^0(t) \right\| \to \min_{U(t) \subset D_U} ; \quad (3)$$

$$E(U,t) = M_O(R,U,t) ; \quad (4)$$

$$dR(t)/dt = M_R(R,U,t) ; \quad (5)$$

$$R(t) \subset D_R(U,t) ; \quad (6)$$

$$t = t_1, t_2, \ldots t_T$$

In this case: $M_O(U,t)$ - is the observation model that allows calculating estimates of the values of indicators for the scenario for the economic development of the regional economy and the fuel and energy sector:

$$U(t) = \begin{bmatrix} U_{econ}(t) \\ U_{FEC}(t) \end{bmatrix}, \quad U(t) \subset D_U , \quad (7)$$

where $U_{econ}(t)$ - the vector of parameters for the development of the regional economy (the scenario for the economic development); $U_{FEC}(t)$ - the vector of parameters for the development of the fuel and energy complex (the scenario for the development of the fuel and energy complex); D_U - the space of managerial decisions;

$R = [r_1, r_2, ..., r_m]^T$ - the vector of regional resources;

$M_R(R,U,t)$ - the model of the region;

$D_R(U,t)$ - resource constraints.

2.2. Methods of solution

The solution of the problem (3) - (6) largely depends on the chosen system of indicators (1) and objectives set for them (2), which should answer the following question: What economic development is considered energy efficient from the point of view of the efficiency of production, transformation, distribution and final consumption of fuel and energy resources? In forming the system of economic indicators E_{econ}, the authors drew on the proposals of the OECD Commission [26] and the Stiglitz-Sen-Fitoussi Commission [27], which proposes the following welfare components: material living conditions (economic welfare), quality of life (non-monetary welfare characteristic) and sustainable socio-economic system as a condition for its reproduction (reproductive potential of the economy).

In forming the system of energy indicators E_{ener} the authors used Russian legal documents defining the concepts of "energy intensity", "energy efficiency", "energy security" and "energy saving" [28, 29], as well as materials of the European Energy Commission [1]. When selecting energy indicators, the requirements of completeness, consistency, and statistical measurability of indicators were taken into account, that is, that the indicators used are calculated by regional statistics. Taking into account the fact that the latter one is undeveloped, it can be noted that this requirement is a serious restriction.

Since the regional fuel and energy complex is closely connected with other sectors of the economy and society, the model of the fuel and energy complex was developed as part of the model of the regional social and economic activity as a whole. The authors developed the model of the subject of the Russian Federation in the class of CGE-models [30]. The basis of the model of the fuel and energy complex is the regional fuel and energy balance, which links production, conversion and final consumption of all types of fuel and energy resources used in the region. In the formation of the regional fuel and energy balance, the authors used the official methodology for compilation of the regional fuel and energy balance [31] and the fuel and energy balance of the Russian Federation [32], as well as the recommendations of the IEA and Eurostat [33, 34].

Forecasting and strategic planning of the energy-efficient development of the subject of the Russian Federation is reduced to search for coordinated scenarios for the development of the fuel and energy complex and the regional economy, which maximize the objectives of the proposed system of indicators. The search for the optimal solution is carried out by the iteration method using a specially designed solver [35].

3 Problem Solution

3.1. The proposed system of indicators

The proposed system of economic development indicators contains 2 groups of indicators characterizing human welfare and the potential of the regional economy (Table 1).

Table 1. Indicators of economic development

1. The life quality of the population of the region
1. The growth of real cash income of the

population per capita,% to the base year. 2. The replacement ratio for pension income,%. 3. The proportion of the population with incomes below poverty line,%. 4. The decile coefficient of income differentiation. 5. The total area of residential units per resident, sq. m. 6. The total fertility rate, people. 7. The infant mortality rate, per mil. 8. Life expectancy at birth, years. 9. Provision of preschool educational institutions, places for 1000 children of preschool age. 10. The number of recorded crimes per 100 thousand people. 11. Expenditure on education, in % relative to regional GRP.
2. Reproductive potential of the regional economy
12. The share of employed in the economy from the number of labor resources, %. 13. The unemployment rate (according to ILO methodology), %. 14. The rate of accumulation of fixed capital, in % relative to GRP. 15. The degree of depreciation of fixed assets at the end of the year, %. 16. The GRP growth relative to the base year, %. 17. The share of intermediate consumption in output of goods and services, %. 18. The share of high-tech and science-intensive products in GRP, %. 19. The growth of exports (including FER) relative to the base year, %. 20. The share of own revenues in the structure of the regional budget, %. 21. The regional budget deficit, %. 22. The public debt of the region, in % relative to GRP.

Indicators of energy efficiency (energy indicators) characterize the following aspects of the energy-efficient development: energy intensity, energy saving, energy security.

Energy intensity of products, works and services is the ratio of total energy expenses involved in production of products, works and services to the volumes of their production [29]. The most important indicators of energy intensity of the regional economy are energy intensity of GRP, as well as energy intensity of the fuel and energy complex.

Energy saving is the implementation of legal, organizational, scientific, industrial, technical and economic measures aimed at the efficient and economical use of fuel and energy resources and at the involvement of renewable energy sources in the economic circulation. Activities in the field of energy saving are characterized by the following indicators: the actual economy of fuel and energy resources; reduction of fuel and energy losses; reduction of energy intensity of production [29]. In the framework of this research, energy saving was assessed as a reduction in losses of primary and produced fuel and energy resources during their production, conversion and final use.

Energy security is protection of citizens, society, state, economy from the threat of a deficit in providing their energy needs with economically accessible energy resources of acceptable quality, from threats of breaking continuity of energy supply [5]. Ensuring energy security is determined by resource adequacy, economic accessibility, environmental and technological feasibility. Indicators of energy security characterize:

- Security of supply of fuel and energy resources and their reservation;
- Diversification of suppliers and types of supplied fuel and energy resources;
- Energy independence;
- Economic accessibility of fuel and energy resources for all consumers.

The energy indicators used in this research are considered in terms of production and consumption of fuel and energy resources (Table 2). The producer of fuel and energy is the regional fuel and energy complex. Consumers of FER are represented by the following subjects of the regional economy:

- The real sector of the economy (without FEC);
- Government agencies;
- Households.

The subject "Region as a whole" is also considered for indicators characterizing the region-wide efficiency.

Such systematization of indicators allows:

- Highlighting the regional fuel and energy sector and assessing its contribution to the overall energy efficiency of the regional development;
- Assessing the aspects of the energy-efficient development of the region from the point of view of the real economic sector, state institutions and households.

Table 2. Energy efficiency indicators

1. Regional Fuel and Energy Complex
1. The growth of FER production to the base year, %. 2. The share of renewable energy sources in the output of fuel and energy resources, %. 3. The index of changes in energy intensity of the

fuel and energy complex, % of the base year.
4. Specific fuel consumption for electricity supply, kgoe / kW-h.
5. Specific fuel consumption for heat output, kgoe / Gcal.
6. Specific losses of the fuel and energy complex, % of FER.
7. Electricity losses in electric grids from the total volume of electricity supply, %.
8. Losses in heat networks, % of heat production.
9. The degree of capacity rate (use) of enterprises of the fuel and energy complex.
10. Depreciation of fixed assets of the fuel and energy sector, %.
11. The rate of accumulation of fixed capital (investment activity) in the fuel and energy sector, %.
2. The real economy (without FEC)
12. The index of changes in energy intensity of the real economy, % to the base year.
13. The share of enterprises that self-sustaining themselves with energy, %.
14. The proportion of enterprises meeting environmental requirements, %.
3. The non-market services sector
15. The index of changes in energy intensity of the non-market services sector, % of the base year.
16. Expenses of budget funds for consumption of fuel and energy resources, % of regional budget expenditures.
4. Households
17. Consumption of fuel and energy resources per capita [kgoe / person], in % of the base level.
18. Average annual changes in electricity consumption per capita, %.
19. Average annual changes in energy consumption for heating residential buildings, %.
20. The index of changes in the share of household expenditures on FER in total expenditures, % of the baseline.
21. The ratio of household expenditures on fuel and energy resources to the subsistence level, %.
22. The share of worn-out, obsolete residential buildings, %.
5. The region as a whole
23. The index of changes in the energy intensity of GRP of the subject of the Russian Federation, in % of the base year.
24. The self-sufficiency indicator of fuel and energy resources, %.
25. The integral coefficient of energy efficiency (the share of useful FER used).
26. The share of the dominant fuel in gross fuel consumption, %.
27. The ratio of fuel and energy savings to the cost of energy-saving measures.

3.2. The model of the fuel and energy complex in the regional model

As the model of the subject of the Russian Federation, the authors developed the model in the class of CGE-models and it was used for making regional forecasting [30]. In this model, the regional economy is divided into a set of economic agents along the boundaries of sections and major classes of economic activity of OKVED [36] adding such agents as: "households", "public authorities", "external environment," and the agent "invisible hand of the market", responsible for the equilibrium of supply and demand in product markets.

Simulated economic agents produce one or more products from the basic set that are sold within the region or exported. At the same time, agents acquire necessary intermediate products (including necessary energy resources) and production factors both within the region and import, taking into account resource and budgetary constraints. The following basic set of conditional products is used in the regional model: 1 - intermediate goods and services (including fuel and energy resources used for processing, transformation and end use); 2 - investment goods and services; 3 - consumer goods and services (including FER used by the population); 4 - infrastructure services; 5 - public services; 6 - labor services.

Economic agents associated with production, conversion and processing of fuel and energy resources are combined into the fuel and energy complex model, which is represented by three sectors (Figure 1). In Figure 1, thick arrows indicate the flows of fuel and energy resources, while thin ones show cash flows. Table 3 lists sectors and related activities of the FEC model.

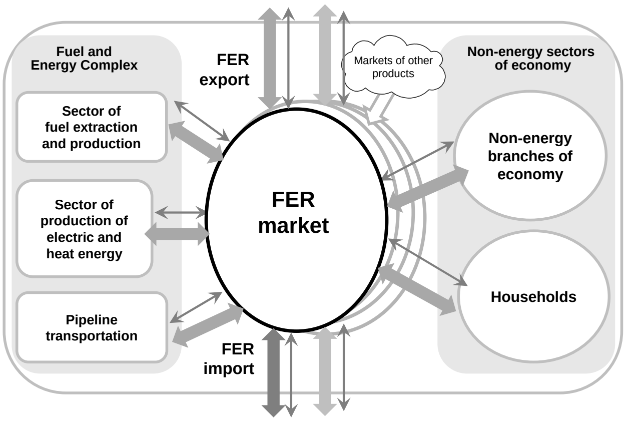

Fig. 1. The model of the fuel and energy sector as an integral part of the regional economy model

Table 3. Sectors and activities of the fuel and energy complex model

Sectors	Type of activity for OKVED [36]
The sector of fuel extraction and production	05. Coal mining 06. Extraction of crude oil and natural gas 09. Provision of services in the field of mining operations 19. Manufacture of coke and refined petroleum products 35.2. Production and distribution of gaseous fuels
The sector of electric and heat energy production	35.1. Electricity production, transmission and distribution 35.3. Production, transmission and distribution of steam and hot water
Pipeline transportation	49.50.1.Transportation oil and oil products through pipelines 49.50.2.Transport of gas and products of its processing through pipelines

In the fuel and energy complex, the following basic set of fuel and energy resources is used: coal, firewood, other solid fuel, oil and gas condensate, natural gas, hydropower, nuclear energy, other natural energy resources, fuel oil, diesel fuel, motor gasoline, gas of oil and gas refineries, dry gas, liquefied gas, other petroleum products, electricity, thermal energy.

The activities of economic agents that make up the model describe bi-directional generalized production functions that, on the one hand, form the supply of agents in relevant markets, and on the other, generate demand for intermediate products (including fuel and energy resources) and products that are production factors, in accordance with technological matrices of agents. The generalized production function of the economic agent $j \in J_{FEC}$ belonging to the fuel and energy complex forms the following flows of resources and money:

1 - the flow of produced FER:

$$X_j^{out}(t) = \min\{X_j^{plan}(t), X_j^{pot}(t), X_j^{dem}(t)\}; \quad (8)$$

2 - the flow of purchased factors of production:

$$X_j^d(t) = A_j(t) X_j^s(t); \quad (9)$$

3 - the flow of funds received from the output of FER:

$$q_j^s(t) = X_j^{out}(t) P_j^T(t); \quad (10)$$

4 - the flow of funds paid for the supply of intermediate products and factors of production:

$$q_j^d(t) = X_j^d(t) \hat{P}_J^T(t). \quad (11)$$

Where: $X_j^{out}(t)$ – the vector-column of the current output of FER for the j-th agent (in natural units);

$X_j^{plan}(t)$ – the vector-column of the planned output of FER, which is specified in the scenario;

$X_j^{pot}(t)$ – the potential output of FER of the j-th agent, as determined by the state of the main production factors;

$X_j^{dem}(t)$ - the vector of demand for FER produced by the j-th agent, from other economic agents, including non-residents;

$X_j^d(t)$ - the vector-column of purchased necessary intermediate products (including FER) and production factors;

A_J - the technological matrix of the j-th agent that characterizes the costs of intermediate products (including FER) and production factors per unit of produced FER;

$q_j^s(t)$ - funds received by the agent from the output of FER;

$q_j^d(t)$ - funds paid by the agent to purchase the necessary intermediate products (including FER) and production factors;

$P_J(t)$ - the vector-column of prices set by the j-th agent for the produced fuel (producer prices);

$\hat{P}(t)$ - the vector-column of fuel prices for buyers in the fuel and energy market (buyers' prices).

The potential output of the j-th agent is calculated by the formula:

$$X_j^{pot}(t) = B_j \sqrt{k_j(t) l_j(t) g_j(t)}, \quad (12)$$

where B_j - is the technological vector linking the scale of the output of FER with the values of production factors; $k_j(t)$ - the total value of fixed assets of the j-th agent; $l_j(t)$ - the number of employees; $g_j(t)$ - the growth rate of the total labor productivity and capital of the agent.

In the regional model, the equilibrium in the markets of conditional products, including FER markets, provides the product-sector balance (PSB) constructed within the framework of the 2008 SNA [37]. At the same time, balance relations are formed for all conventional products used in the model, including for all 15 types of fuel and energy resources listed above.

In particular, the balance of the i-th type of FER $(i \in I_{FER})$ in its natural form (in physical units) has the following form:

$$\begin{aligned} &x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t) = \\ &= x_i^{out}(t) - x_i^{\exp}(t) + x_i^{imp}(t) - \Delta x_i(t) \end{aligned} . \quad (13)$$

The left side of the balance sheet (13) shows the natural demand of the regional economy for the i-th type of FER for: conversion to electricity and heat (x_i^{d1}), processing into other fuels (x_i^{d2}),use as non-energy raw materials (x_i^{d3}); final consumption (x_i^{d4}).The values x_i^{d1}, x_i^{d2} are calculated as the total acquisition of the i-th type of FER by agents that are part of the fuel and energy sector. Values x_i^{d3} and x_i^{d4} are calculated as production consumption of the i-th type of FER by petrochemical industries and as the total final consumption of the i-th type of FER by all agents of the economy, respectively.

The right-hand side of the balance equation (13) shows the proposal of the i-th type of FER in the regional market: x_i^{out} - the total output of the i-th type of FER in the region by all FEC agents; $x_i^{\exp}$ - export of the i-th type of FER by producers; x_i^{imp} - purchase of the i-th type of FER for import; Δx_i - changes in reserves of the i-th type of FER.

The balance in the cost for the i -th type of FER ($i = 1,2,...,15$) will be presented as follows:

$$\begin{aligned} &(x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t))\hat{p}_i(t) = \\ &= (x_i^{out}(t) - x_i^{\exp}(t) - \Delta x_i(t)) p_i(t) + \\ &+ x_i^{imp}(t)\hat{p}_i(t) + \Delta q_i \end{aligned} \quad (14)$$

Where: $\hat{p}_i$ - the average price of the i-th type of FER in the FER market (the average buyer price); p_i - the average producer price of the i-th type of FER; Δq_i - the total transport and trade markup of the i-th type of FER.

The fuel and energy balance (13) - (14), formed within the framework of the fuel and energy complex model, is part of the overall PSB (the product-sector balance), which is the balance of balances, and allows modeling the mutual influence of the fuel and energy complex and the rest of the economy through inter-balance relations.

The developed model was calibrated on the statistical material of the Samara region. The goal of this calibration was to assign to exogenous parameters of model numerical values that best correspond to real values of similar parameters. In particular, during calibration, the parameters of technological matrices A_j and B_j of economic agents, the coefficients of the cost elasticity of fuel and energy resources for output, the tariffs and climatic conditions were estimated.

When constructing the composite fuel and energy balance of the subject of the Russian Federation, the single-product balances of fuel and energy resources (13) and (14) were brought into line with methodological developments of the Ministry of Energy of the Russian Federation and Rosstat [31, 32], which in their last documents do not differ fundamentally from the generally accepted methodology in the world compilation of IEA / Eurostat balances [33, 34].

The developed models formed the basis for the system of support of management decisions for regional authorities (hereinafter - the System). The system is intended for model approbation of management decisions of regional leaders in the tasks of increasing energy efficiency and energy security of the regional economy. The system supports the following information technologies:

- Forecasting of the balanced development of the economy and the fuel and energy sector;
- Search for the best energy-efficient scenario for the regional development.

3.3. Technology for forecasting of the balanced development of the economy and fuel and energy complex

Forecasting of the energy-efficient development of the region is carried out on the basis of the scenario approach, within which it is ensured that forecasts of energy consumption and production of energy resources are compared and iteratively agreed on the main types of fuel and energy resources. The integration function in the process of coordinating the demand and supply of fuel and energy resources is played by the forecasted fuel and energy balance that ensures the formation of the consistent and mutually agreed system of forecasts for the regional economic development, consumption and production of key fuels and energy, and the production potential of the fuel and energy sector. The forecasting procedure looks like two interconnected circuits: the forecasting circuit of the regional economy and the forecasting circuit of the fuel and energy complex. In the first circuit, the scenario for the development of the regional economy is developed expertly $U_{econ}(t)$, containing empirical assumptions about the behavior of economic agents (except for the fuel and energy complex) on the horizon of forecasting: the demographic development scenario; expected indices of production and indices-deflators of prices and tariffs; parameters of tax, investment and budgetary policy. Based on the scenario $U_{FEC}(t)$, the gross output, intermediate consumption and added value in the sectors of the regional economy are projected on the model of the regional economy and the primary forecast of energy consumption in these sectors is calculated - the left side of FER balance sheets (13). As a result of these calculations, general requirements for FER components $i \in I_{FER}$ are formulated in kind:

$$x_i^d(t) = x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t)\,; \quad (15)$$

These requirements for FER are detailed as requirements for the production base development of the relevant fuel and energy sector. Further, taking into account the forecast of tariffs for fuel and energy resources, effective demand for FER components $i \in I_{FER}$ in economic sectors is estimated in monetary terms:

$$q_i^d(t) = (x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t))\,\hat{p}_i(t) \quad (16)$$

And left parts of value balances of FER are formed (14).

In the second circuit, according to the scenario for the development of the fuel and energy complex $U_{FEC}(t)$, the development of production capacities (12) for each fuel and energy sector is predicted on the FEC model, taking into account the expected forecast of investment in fixed capital of the fuel and energy complex and the growth of energy tariffs, based on which the potential production of energy resources is predicted in physical units:

$$x_i^{out}(t),\ i \in I_{FER}\,. \quad (17)$$

Further, the potential supply of fuel and energy resources is formed in the regional market, taking into account the obligations of regional FER producers for their export and coming-out to other regions of the Russian Federation:

$$x_i^s(t) = x_i^{out}(t) - x_i^{\exp}(t) + x_i^{imp}(t)\,. \quad (18)$$

Based on (18), taking into account the forecast of tariffs for the components of FER, the FER proposal is calculated in money terms:

$$q_i^s(t) = (x_i^{out}(t) - x_i^{\exp}(t) - \Delta x_i(t))\,\hat{p}_i(t) + x_i^{imp}(t)\,p_i(t) + \Delta q_i(t) \quad (19)$$

The components (18) and (19) form the right-hand parts of balance sheets of fuel and energy resources (13) and (14).

The calculated long-term demand for FER (15), (16) is element-wise linked to the possibilities of their supply (18) and (19). If on the forecasting horizon there is $t \in [t_1, t_T]$

$$\begin{cases} x_i^d(t) \le x_i^s(t) \\ q_i^d(t) \le q_i^p(t) \end{cases}, \quad (20)$$

this means that the potential of the fuel and energy complex provides the regional needs for the *i*-th type of FER, and tariffs for FER form the supply of the resource at the demand level providing development. The oversupply

$$\Delta x_i(t) = x_i^p(t) - x_i^d(t) \quad (21)$$

can be eliminated by: increasing the export of the *i*-th type of FER; decreasing the output of the resource; reducing the import of the resource; replacing the *i*-th type of FER of scarce resources. Decisions to adjust the excess supply are formed at the level of adjusting the scenarios for the development of the fuel and energy complex $U_{FEC}(t)$.

If for some moments of time $t \in [t_1, t_T]$

$$\begin{cases} x_i^d(t) > x_i^s(t) \\ q_i^d(t) \le q_i^s(t) \end{cases}, \quad (22)$$

this means that the potential of the fuel and energy sector does not meet the regional needs for the *i*-th type of FER. It is necessary either to increase the supply potential of the *i*-th type of FER, or to adjust economic growth, or to do both. The increase in the supply potential is possible due to: the increase in the output of the resource; the export reduction of the *i*-th type of FER; the increase in the import of the resource; substitution of *i*-th of type of FER from other energy resources.

Increasing the potential of the fuel and energy complex requires well-defined development resources that are limited and can be easily estimated. The import / export operations are evaluated on the model of the external environment.

Reducing consumption of FER by the economy can be achieved by adjusting economic growth downwards, as well as by carrying out measures for energy saving, reducing the specific energy intensity of production and increasing the energy efficiency of technologies used.

Management decisions to eliminate the

imbalance between the demand and supply of FER are formed at the level of adjusting the scenario conditions for the development of FEC $U_{FEC}(t)$ and the economy $U_{econ}(t)$ within the framework of balance equations (13), (14).

If for some $t \in [t_1, t_T]$

$$\begin{cases} x_i^d(t) \le x_i^s(t) \\ q_i^d(t) > q_i^s(t) \end{cases}, \quad (23)$$

this means that the tariffs for the *i*-th type of FER form the supply of the resource at the level that does not correspond to the solvent demand of the region for the *i*-th type of FER. It is necessary to reduce the tariff for this type of FER within the framework of the balance equation (14).

The correlation procedure of the scenarios for the development of the economy $U_{econ}(t)$ and the fuel and energy complex $U_{FEC}(t)$ is carried out by a step-by-step iterative correction of the initial scenario (the initial estimate)

$$U^0(t) = [U^0_{econ}(t), U^0_{FEC}(t)]^T, \quad (24)$$

given by the researcher. The correction tools are scenario parameters, the changes of which are aimed at coordinating the supply and demand for all types of resources (including fuel and energy resources) within the framework of the formation of the general PSB in kind and in value form (Tsybatov, 2015b). In the process of iterative coordination, the consistent scenario for the development of the regional economy and the fuel and energy complex is being formed:

$$U^*(t) = [U^*_{econ}(t), U^*_{FEC}(t)]^T. \quad (25)$$

3.5. The technology to find the best scenario for the energy-efficient development

The objectives of the energy-efficient development of the subject of the Russian Federation are set in the form of targets (2) for indicators of economic development and the chosen system of energy indicators (see Table 1, 2). The procedure for setting objectives for energy indicators is an independent task that goes beyond the scope of this article. The authors introduced the criterion characterizing the total relative deviation of the common indicator vector

$E(t) = [E_{econ}(t), E_{ener}(t)]^T =$

$= [e_1(t), e_2(t), ..., e_N(t)]^T$ from fixed targets

$E^0(t) = [E^0_{econ}(t), E^0_{ener}(t)]^T =$

$= [e^0_1(t), e^0_2(t), ..., e^0_N(t)]^T$ in measuring points $t \in [t_1, t_2, ..., t_T]$:

$$\Phi(U,t) = \left\{ \sum_{i=1}^{N} \left\{ g_i \sum_{k=1}^{T} \left| \frac{e_i(U,t_k)}{e_i^0(t_k)} - 1 \right| \right\} \right\}. \quad (26)$$

Where N - the total number of indicators (economic and energy); g_i - the value (weight) of the *i*-th indicator; T - the number of points in the interval of strategic planning.

Then the task to find the option of the energy-efficient development (3) - (6) will be reduced to the following optimization problem: to find the acceptable scenario for the development of the regional economy and the fuel and energy sector, which minimizes the general "dissatisfaction" with not achieving the objectives set for indicators at the points $t = t_1, t_2, ..., t_T$ on the horizon of strategic planning $[0, t_T]$

$$\min_{U(t) \subset D_U} \Phi(U(t)) = = \min_{U(t) \subset D_U} \left\{ \sum_{i=1}^{N} \left\{ g_i \sum_{k=1}^{T} \left| \frac{e_i(U(t_k))}{e_i^0(t_k)} - 1 \right| \right\} \right\} \quad (27)$$

Where the indicators $e_1(U(t))$, $e_2(U(t))$, ..., $e_N(U(t))$ are calculated on the model of the region when solving the direct problem of scenario forecasting (4) - (6) for the development scenario $U(t)$ belonging to the space of management decisions D_U, given in the form of admissible intervals to regulate the scenario parameters:

$$U^{\min}(t) \le U(t) \le U^{\max}(t). \quad (28)$$

Let us imagine the general scenario $U(t)$ in the form of $L \times T$ control matrix U, where $L = m + n$ is the combined vector dimension of scenarios for the development of the regional economy $U_{econ} = [u_{econ,1}, u_{econ,2}, ..., u_{econ,m}]^T$ and the scenario parameters for the development of the fuel and energy complex $U_{FEC} = [u_{FEC,1}, u_{FEC,2}, ..., u_{FEC,n}]^T$, and T is the number of points in the interval of strategic planning:

$$\mathrm{U} = \begin{bmatrix} u_{1,1}, & u_{1,2}, & ..., u_{1,T} \\ u_{2,1}, & u_{2,2}, & ..., u_{2,T} \\ \multicolumn{3}{c}{\dots\dots\dots\dots\dots} \\ u_{L,1}, & u_{L,2}, & ..., u_{L,T} \end{bmatrix}. \quad (29)$$

The authors denote the initial estimate $\mathrm{U}^{(0)}$ of the control matrix U (the base scenario) and represent the control matrix U in the following form:

$$\mathrm{U} = \mathrm{U}^{(0)} \otimes K \,. \qquad (30)$$

Where $K = \left\| k_{i,j} \right\|_{L \times T}$ is $L \times T$ correcting matrix; $\otimes$ - the symbol of element-wise multiplication of matrices.

The record (30) allows reducing the problem (27) to search for the optimal correcting matrix K^{opt}. The article [35] represents the effective method of searching for the optimal matrix K^{opt}, which allows solving such problems as (27) for many dozens of the objectives N and hundreds of control variables L in acceptable time. The solver, developed on the basis of the matrix method, automatically generates development scenarios:

$$\mathrm{U}^{\mathrm{opt}} = \mathrm{U}^{(0)} \otimes K^{opt} \rightarrow \begin{bmatrix} U_{econ}^{opt}(t) \\ U_{FEC}^{opt}(t) \end{bmatrix}, \qquad (31)$$

when the values of energy indicators achieve the set objectives E^0 as close as possible, taking into account the importance of these indicators (weights g_i) and resource constraints on control actions.

4. Conclusion

Management decisions in the economy and energy cannot fundamentally be one-time and rigid, they should be systematically reviewed in relation to changing conditions with the use of constantly operating systems to support management decisions that allow setting and resolving urgent problems of the energy-efficient development. The system developed by the authors, that implements information technology for forecasting the balanced energy-efficient development of the economy and the fuel and energy complex, fills the existing gap in the market for management decision support systems for regional authorities. The system ensures approval and iterative coordination of energy consumption and energy production forecasts based on the formation of the regional fuel and energy balance, as well as the search for the best scenario of the energy-efficient development.

Due to the fact that management decisions in the economy and energy can contradict each other, it is proposed to identify the best ratio between indicators of general economic and energy efficiency within the framework of the single task of multi-criteria optimization, where, along with general economic objectives, energy efficiency guidelines are set. The choice of the energy indicator system should answer the following question: What development is considered to be energy efficient? Based on the analysis of literature sources and regulatory documents the authors developed the system of energy indicators that characterizes the development of the fuel and energy complex and the regional economy from the standpoint of energy efficiency (energy intensity, energy saving and energy security). The advantages of the proposed system of energy indicators are its completeness, consistency and statistical computability. The novelty of the proposed methodology for the search for the best scenario of energy-efficient development is that the regional fuel and energy balance, formed within the framework of the fuel and energy complex model, is part of the overall regional product-sector balance formed for the region as a whole and is the balance of balances. This allows modeling the mutual influence of the fuel and energy complex and the rest of the economy through inter-balance relations.

It should be noted that the results of searching for the scenario of the energy-efficient development (31) largely depends on decisions made by the Researcher, since he forms the space of management decisions (28), and also sets weight factors (g_i) for indicators of the economy and energy. The control of weight coefficients of indicators largely changes the conditions of the problem (27), while the indicator with a large weight has the greatest opportunities to approach its objective by suppressing indicators with smaller weights. The solution of the problem will be different depending on what is more important for the Researcher - "doubling GRP", "increasing incomes of the local budget" or "increasing energy efficiency of the economy." Through the weight coefficients of energy indicators, the Researcher has the opportunity to arrange "energy efficiency", correcting the solution of the general problem of searching for the scenario of the energy-efficient development (27) in the right direction.

Direct participation in making management decisions required the authors to fully comply with the conceptual information structure of the model tools of the regional statistics and to maximize the use of regional statistical data in calculations. Modeling tools were calibrated on the statistical material of the Samara region. The main problems were incompleteness of reporting data, their inconsistency, as well as the transition of domestic statistics in 2016 to a new classification of economic activities [36]. To solve the problems of incompleteness and inconsistency of the data, the authors developed the tool for supplementing and balancing the data. The problems associated with the transition to a new OKVED were solved by prototyping up missing data on new classes of economic activity before the official statistics appeared.

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References

[1] Energy Efficiency. *European Commission*. available at: https://ec.europa.eu/energy/en/topics/energy-efficiency

[2] Good practice in energy efficiency. For a sustainable, safer and more competitive Europe. *European Commission*, available at: https://ec.europa.eu/energy/sites/ener/files/documents/good_practice_in_ee_-web.pdf

[3] Good practice in energy efficiency. Commission staff working document. - *European Commission.* Brussels, 30.11.2016. - SWD(2016) 404 final, available at: http://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1490870135947&uri=CELEX:52016SC0404

[4] The energy strategy of Russia for the period up to 2030, available at: https://minenergo.gov.ru/node/1026

[5] Draft Energy Strategy of the Russian Federation for the period up to 2035 (revised as of 01.02.2017) available at: http://minenergo.gov.ru/node/1920

[6] R. Young, S. Hayes, M. Kelly, S. Vaidyanathan, S. Kwatra, R. Cluett, G. Herndon. The 2014 International Energy Efficiency Scorecard. *American Council for an Energy-Efficient Economy*. July 2014. Report Number E1402.

[7] Accelerating energy efficiency initiatives and opportunities in Eastern Europe, Caucasus and Central Asia. *Copenhagen Centre on Energy Efficiency* (2015). - Copenhagen. Denmark, available at: http://www.energyefficiencycentre.org

[8] Worldwide Trends in Energy Use and Efficiency: Key Insights from IEA Indicator Analysis // *OECD/IEA*. – Paris, 2008. - 91 p.

[9] Borges, A.R., & Antunes, CH. (2003). A fuzzy multiple objective support model for energy-economy planning. *European Journal of Operational Research*, 145, pp. 304-316.

[10] SCANER - a model and information complex. ERI RAS, (2011), 74 p.

[11] Psarras, J., Capros P., & Samouilidis J. E. (1990). Multiobjective programming. *Energy, 15*, pp. 583–605.

[12] Greening, L.A., & Bernow S. (2004). Design of coordinated energy and environmental policies: use of multi-criteria decision-making. *Energy Policy*, 32, 721-735.

[13] Becalli, M., Cellura, M., & Mistretta, M. (2003). Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology. *Renewable Energy*, 28, 2063-2087.

[14] Capros, P., Karadeloglou, P., Mentzas, G. & Samouilidis, J. E. (1990). Short and medium-term modeling and problems of models linkage. *Energy*, 15, pp. 301–324.

[15] Jebaraj, S., & Iniyan, S. (2006) A review of energy models. *Renewable and Sustainable Energy Reviews*, 10, pp. 281–311.

[16] Dixon, P.B., Koopman, R.B. & Rimmer, M.T. (2013). The MONASH Style of Computable General Equilibrium Modeling: A Framework for Practical Policy Analysis. *Chapter 2 in the Handbook of Computable General Equilibrium Modeling. Dixon, P.B. & Jorgenson, D.W. (eds.). North-Holland, Amsterdam*, pp. 22-103.

[17] Wickens, M. (2008). Macroeconomic theory: a dynamic general equilibrium approach. *Princeton: Princeton University Press*, 477 p.

[18] Adams, P.D., & Parmenter, B.R. (2013). Computable General Equilibrium Modeling of Environmental Issues in Australia: Economic Impacts of An Emission Trading Scheme. *Chapter 9 in the Handbook of Computable General Equilibrium Modeling Dixon, P.B. & Jorgenson, D.W. (eds.), NorthHolland, Amsterdam*, pp. 553-657.

[19] Bohlmann, H.R., Van Heerden, J.H, Dixon, P.B., & Rimmer, M.T. (2015). The Impact of the 2014 Platinum Mining Strike in South Africa: An Economy-Wide Analysis. *Economic Modelling*, Volume 51, pp.403-411.

[20] Farajzadeh, Z., & Bakhshoodeh, M. (2015). Economic and environmental analyses of Iranian energy subsidy reform using Computable General Equilibrium (CGE)

model. *Energy for Sustainable Development.* Volume 27, August 2015, pp. 147-154.

[21] Jorgenson, D.W, Goettle, R.J, Ho, M.S & Wilcoxen, P.J. (2013). Energy, the Environment and US Economic Growth. *Chapter 8 in the Handbook of Computable General Equilibrium Modeling. Dixon, P.B. & Jorgenson, D.W. (eds.). North-Holland, Amsterdam*, pp. 475-552.

[22] Evolution of the world energy markets and its consequences for Russia (2015). Ed. A.A. Makarova, L. M. Grigoryeva, & Mitrova, T. A. Moscow: *ERI RAS-AC under the Government of the Russian Federation*, 400 p.

[23] Bykova, E. V., & Grodetsky, M. V. (2011). Analysis and monitoring of energy security and forecasting the values of indicators by the method of conditional nonlinear mathematical programming. *The economy of the region*, Issue 3, pp. 234-240.

[24] Ratmanova, I.D. & Kuleshov, M.A. (2014). Formation of the consolidated fuel and energy balance within the framework of the regional information and analytical system. *Bulletin of Ivanovo State Energy University*, Issue 4, pp. 1-7.

[25] The Federal Law as of June 28, 2014 No. 172-FZ "On Strategic Planning in the Russian Federation". URL: http://base.garant.ru/70684666/

[26] Stiglitz, J.E., Sen, A. and J. Fitoussi. 2009. "Report by the Commission on the Measurement of Economic Performance and Social Progress," *CMEPSP*, available at: http://www.stiglitz-sen-fitoussi.fr/documents/rapport_anglais.pdf

[27] OECD Framework for Statistics on the Distribution of Household Income, Consumption and Wealth (2013), available at: http://www.oecd.org/statistics/302013041e.pdf

[28] ГОСТ 31607-2012 Энергосбережение. Нормативно-методическое обеспечение. Основные положения.

[29] GOST 31532-2012 Energy saving. Energy efficiency. Composition of indicators. General provisions.

[30] Tsybatov, V. A. (2015). Strategic planning of the regional development: methods, models, information technologies. *Regional economy. Theory and Practice*, Issue 27 (July), pp. 36 - 53.

[31] The Ministry of Energy of the Russian Federation. Order No. 600 of 14 December 2011 "On Approving the Procedure for Drawing Up Fuel and Energy Balances of Subjects of the Russian Federation and Municipal Formations" (as amended on November 19, 2015) available at: http://docs.cntd.ru/document/902320537

[32] The Federal Service of State Statistics. Order No. 229 of April 4, 2014. "On the approval of the official statistical methodology for the compilation of the fuel and energy balance of the Russian Federation." available at: http://docs.cntd.ru/document/499089559

[33] Key World Energy STATISTICS. *OECD/IEA, 2014 International Energy Agency (IEA).* available at: http://www.energyconf.ir/pdf/6.pdf

[34] Energy balances of non-OECD countries. *OECD. (2015). Revised edition. Database documentation. URL:* http://wds.iea.org/wds/pdf/WEDBAL_documentation.pdf

[35] Tsybatov, V. A. (2015). Models and methods of the regional development strategy. *Bulletin of Samara State University of Economics*, Issue 3 (125), pp. 49-66.

[36] All-Russian classifier of economic activities (OKVED 2). OK 029-2014 (NACE Rev. 2), available at: http://xn---2-dlci2ax1i.xn--p1ai/

[37] The system of National Accounts 2008. (2012). Ed. Prof. Yu. N. Ivanova. European Commission, UN, IMF, OECD, WB. New York, 764 p.