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Tooling of Modeling and Strategic Planning of Energy-Efficient Development of the Regional Fuel and Energy Complex

Gabibulla R. Khasaev [1*], Vladimir A. Tsybatov [1]

[1] Samara State University of Economics, RUSSIA

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ABSTRACT

The article is devoted to the relevant problem of regional development – elaboration of methodical tooling and information technologies of macroeconomic modeling and strategic planning of energy-efficient development of the Russian Federation regions. The task of energy-efficient development is solved through the search of the agreed scenarios of development of the Fuel and Energy Complex (FEC) and economy of the region; the scenarios which help to achieve the maximum approach to the targets for the offered system of energy indicators. The authors developed a dynamic multisectoral model of the Fuel and Energy Complex, which reproduces interconnected production processes, processing, transportation and use of all types of fuel and energy resources in the region. The methodology of formation of the multiple regional fuel and energy balance (FEB) is offered. It allows predicting energy intensity and energy consumption of economy, including, energy consumption of GRP, estimating energy security and energy efficiency of economy, and revealing "narrow" places and threats in FEC development. The methods and algorithms allowing solving the problems of multi-purpose management of FEC for many tens of the purposes and hundreds of control variables are developed for estimation of achievability of the purposes of energy-efficient development of the Russian Federation regions. On the basis of the methods and models, presented in the article, information technologies of situational forecasting and strategic planning are realized in the form of predictive and analytical system, aimed at support of managerial decisions of regional authorities in the task of energy efficiency and energy security increase at the Russian Federation regions. The developed tooling was calibrated on the statistical material of the Samara region and was tested while solving practical tasks of strategic planning of energy-efficient development of the Russian Federation regions.

Keywords: energy-efficient development, the Russian Federation regions, fuel and energy complex, fuel and energy balance, energy indicators, modeling, CGE-models, forecasting, strategic planning

INTRODUCTION

Establishing a Context

The strategic purpose of the regional energy policy is creation of a regional energy security system, being steady and capable of self-regulation. It should be created with due consideration to optimization of the territorial structure of production and Fuel and Energy Resources (FER) consumption. Insufficient development of mechanisms of Fuel and Energy Balances (FEB) usage for forecasting and management of FEC development at the

* **Correspondence:** Gabibulla R. Khasaev, *Department of Regional Economy and Management, Samara State University of Economics, Samara, Russia.*

gr.khas@mail.ru

federal and regional levels is one of the main problems solved in the Energy Strategy of Russia for the period until 2035 [1]. In fact, it is about the need to support experts with mathematical models, methods and computing means for solution and mutual coordination of the hierarchy of multicriteria tasks, arising in energy management in the conditions of uncertainty. That is why the predictive and analytical systems of managerial decisions support are in great demand at the regional level nowadays. Such systems would allow regional authorities to form fact (reporting) and predictive FEB. On their basis, it will be possible to estimate energy efficiency and energy security of the regional economy, including energy consumption of GRP, to carry out scientifically based forecasts of consequences of implemented managerial decisions, to form balanced systems of goals of regional energy-efficient development and to estimate their achievability.

Literature Review

A large number of managerial decision support systems in the energy sector is described in literature, starting from the systems, which scope is limited by the very certain energy carriers control, and finishing with the difficult systems, which consider the energy sector as an integral part of economy [2, 3]. The existing systems are characterized by a big variety of decision-making models, their reviews, discussions and comparison are given in the articles [4, 5, 6]. The theoretical and empirical problems, arising while creating the systems of «energy – economy» models are investigated in the article [7]. These models are used for short-term and medium-term forecasting (Hermes-Midas systems). The most important component of any managerial decision support system in the energy sector is the FEC model and its connection with other sectors of economy. The review of more than 250 energy models was made in article [8]; the mentioned models are widely used in different countries for analysis and forecasting of the energy sector development**.** Optimization models were analyzed, in particular: different types of models of FEB optimization; stepped energy system optimization models; the models minimizing energy consumption of GDP, taking into account various restrictions; planning models of energy supply and demand with the use of the multicriteria technique of programming in the traditional Leontev's model of "expense-release". A special place in the literature on modeling is given to computable general equilibrium (CGE) models [9, 10]. These models are widely used for analysis of the consequences of implemented managerial decisions due to their ability to model reaction of the system to external influences [11]. In the energy sector, CGE-models appeared as useful empirical tools, allowing estimating scales of economic consequences of the energy and environmental policy [12, 13, 14, 15].

However, the Russian research in the sphere of modeling and forecasting of the energy sector are of great pragmatic interest for us. The reason is that they consider the features of national institutions of management and statistical description of modeling subjects more properly. Currently, the technology of modeling and forecasting of the energy sector, developed at the Institute for Energy Studies of RAS (INES RAS), deserves greater consideration [3]. This technology is successfully used for forecasting of both Russian and the world energy sector [16]. The main feature of this technology is the formation of consistent and mutually agreed forecast system of the country's economic development, volumes of consumption and production of the main types of fuel and energy, and also financing of certain FEC branches. Iterative matching in the forecast system is made through the energy balances, formed for the country in general and for certain regions; production characteristics and financial balances of FEC branches, correlating to interindustry balances of the national economy.

The analysis of the literature sources shows that currently there are no other systems like those, developed at INES RAS at the regional level. Some domestic developments in formation of the regional FEB, for example, [17, 18] do not fully correspond to the urgent needs of the regional development. In particular, they do not have the tooling for formation of forecast FEBs, the tasks of strategic goal-setting for FEC development are not being solved, that is especially relevant in connection with adoption of the Federal Law on Strategic Planning [19].

Aim of the Study

The main goal of this research is development of methods, models and information technologies for the support of regional authority managerial decisions in the task of energy efficiency and energy security increase of the regional economy. The developed means are presented in the form of a managerial decision support system (further – the System), which architecture is shown in **Figure 1**. The system performs functions of strategic goal-setting, long-term forecasting and also search of the best scenarios of energy-efficient development in the context of the stated purposes. The System consists of:

- the model of activity of the region, reproducing the dynamics of socio-economic processes;
- the FEC model, which concretize the activity of the energy sector as a part of the region model;
- the subsystem of installation and balancing of purposes for indicators of development of FEC and economy of the region;
- the subsystem of formation of managerial decisions (scenarios of development of FEC and economy of the region).

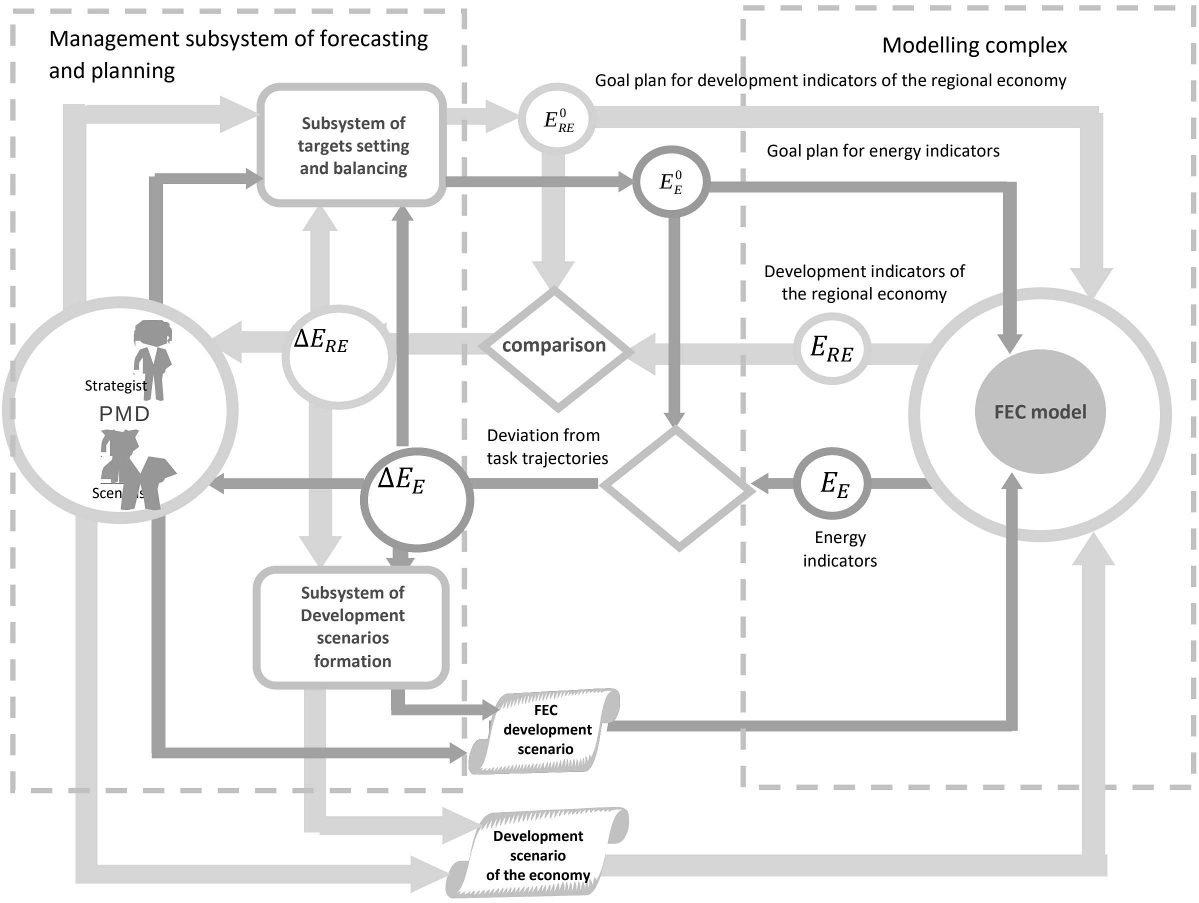

Figure 1. The architecture of managerial decision support in the energy sector

The persons, making decisions (PMD) operate the activity of the System. PMD carry out target setting of energy-efficient development of the constituent territory of the Russian Federation and its solution by means of the System.

When developing methodical means and tools of the System, the following objectives were set and solved:

- development of energy indicators system, characterizing development of FEC and the regional economy from the point of view of efficiency of production processes, transformation, distribution and final consumption of FER;
- development of the methodology of formation of regional reporting FEB - from collecting necessary statistical information to balance sheets creation;
- development of the FEC model of the region as a dynamic multisectoral model as a part of the economy model of the Russian Federation regions;
- development of the information technology, providing convergence and iterative matching of scenario forecasts of energy intensity and production of energy resources in the region by the main types of FER;
- development of tooling for search of the agreed scenarios of FEC and regional economy development, which help to achieve the maximum approach to the targets for the offered system of energy indicators characterizing the regional economy development from the point of view of efficiency of production processes, transformation, distribution and final consumption of all types of FER.

MATERIALS AND METHODS

Formal Goal Setting

Energy-efficient development of FEC has always been identified with economic efficiency of its development and functioning. In literature, great efforts are still made for identification of proper correlations between indicators of general economic efficiency and efficiency of power decisions. Efforts are also put on further expansion of the concept of FEC efficiency, in particular implementation of multipurpose (multicriteria) approaches, which reflect not only economic, but also social requirements of society to the energy sector. In this regard, it is expedient to reduce a problem of energy-efficient development of the region to the search of the agreed scenarios of FEC and regional economy development, which help to achieve the maximum approach to the targets for the offered system of energy indicators. These purposes characterize development of the regional economy as energy-efficient from the effectiveness of production processes, transformation, distribution and final consumption of all types of FER. Let us denote the general system of indicators of regional development

$$E = [E_{RE}, E_E]^T \tag{1}$$

where E_{RE} - the vector of indicators, characterizing socioeconomic development of the region, namely: standard of population well-being and potential of the regional economy;

E_E - the vector of energy indicators, characterizing development of the regional economy from the point of view of energy efficiency.

Let us denote

$$E^0(t) = [E^0_{RE}(t), E^0_E(t)]^T \tag{2}$$

the vector of target values, established for development indicators on the horizon of strategizing $[0, t_T]$ at points $t = t_1, t_2, \dots, t_T$, where the vector of target values for energy indicators $E^0(t)$ is like a goal plan of energy-efficient development. Addition of the vector $E^0_E(t)$ in the general list of the regional purposes (2) gives to the regional development "energy efficient coloring".

It should be noted that goals of energy indicators $E^0_E(t)$ can contradict the purposes of the economy $E^0_{RE}(t)$, for example, the demand of decrease in energy consumption of GRP can contradict the decision to develop power-intensive branches, or export-oriented development can reduce energy security of the economy. Therefore targets of energy-efficient development of the constituent territory of the Russian Federation $E^0_E(t)$ should be balanced with purposes of socioeconomic development $E^0_{RE}(t)$ within the solution of the general task of energy-efficient development. Formally the problem of energy-efficient development of the region (constituent territory of the Russian Federation) can be reduced to the following task of multicriteria optimization:

$$\|E(U,t)\| \to \min_{U(t) \subset D_U}; t = t_1, t_2, \dots, t_T; \tag{3}$$

$$E(U,t) = M_E(R,U,t); \tag{4}$$

$$dR(t)/_{dt} = M_R(R,U,t); \tag{5}$$

$$R(t) \subset D_R(U,t). \tag{6}$$

Here: $M_E(U,t)$- an observation model, allowing calculating values of indicators $E(t)$ for this or that development scenario of the regional economy and FEC:

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

where $U_{RE}(t)$ - the vector of scenario parameters of the regional economy development; $U_{FEC}(t)$ - the vector of scenario parameters of FEC development;

D_U - the space of managerial decisions;

$R = [r_1, r_2, \dots, r_m]^T$ - the vector of region resources;

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

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

Methods of Solution

Solution of the task (3) – (6) mainly depends on the chosen system of energy indicators, which should answer the question what development is considered as energy efficient from the point of view of effectiveness of production processes, transformation, distribution and final consumption of FER. When forming the system of energy indicators, the authors used legal documents defining the notions of "energy consumption", "energy efficiency", "energy security" and "energy saving" [20, 21]. Requirements of completeness, consistency and also statistical measurability of indicators, that means that the used indicators are calculated by the regional statistics, were considered while selecting energy indicators. Taking into consideration insufficient development of the regional statistics, it should be noted that this requirement is a serious restriction.

As FEC of the region is closely connected with other sectors of the economy and aspects of public life, the FEC model was developed as a part of the model of socioeconomic activity of the region in general. The model of the Russian Federation region, developed by the authors in the class of CGE-models, was taken as a basis [22]. The FEC

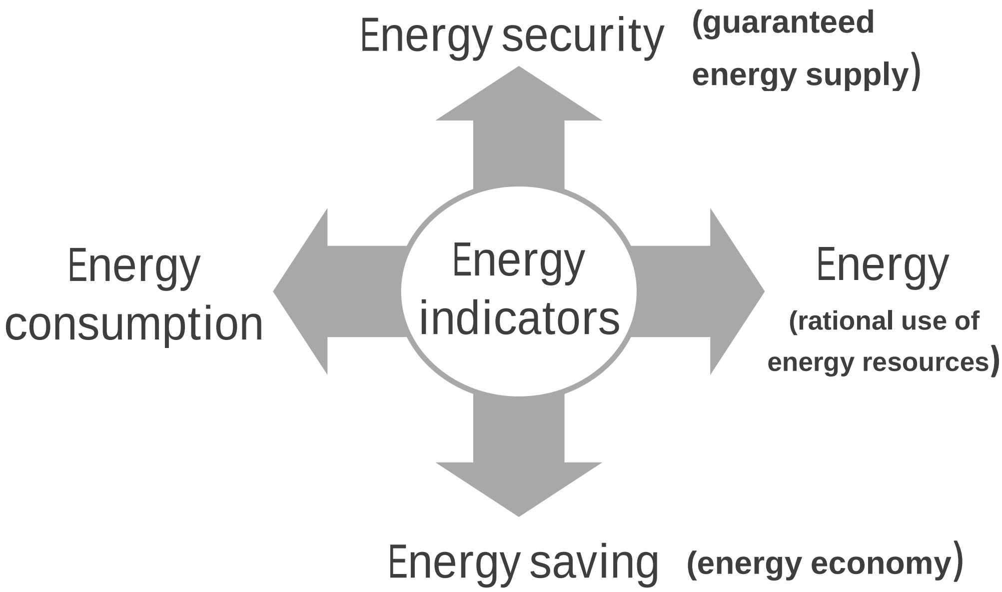

Figure 2. Aspects of energy-efficient development

model is based on the regional Fuel and Energy Balance, connecting together production processes, transformation and final consumption of all types of FER used in the region. The official methodology of FEB creation of RF constituent territories [23] and Russian Federation [24], and recommendations of IEA and EUROSTAT [25; 26] were used while forming the regional FEB.

Forecasting and strategic planning of energy-efficient development of the Russian Federation region is performed in the search of the agreed scenarios of FEC and the regional economy development; the scenarios which help to achieve the maximum approach to the targets for the offered system of energy indicators. Search of an optimal solution is carried out by the iteration method by means of specially developed solver [27].

RESULTS

The Offered System of Energy Indicators

The offered system of energy indicators consists of 4 groups of the indicators, characterizing the following aspects of energy-efficient development: energy consumption; energy efficiency; energy saving; energy security (**Figure 2**).

Energy consumption of goods, work and services is ratio of full energy input on goods, work and services production to their production volume [20]. The most important indicators of regional energy consumption are the power intensity of GRP and also FEC power input.

Energy efficiency is effective (rational) use of energy resources, achievement of economically viable efficiency of energy resources use at the existing level of equipment and technology development and compliance with the requirements to environmental protection [20]. The most important indicators of energy efficiency of the regional economy are those that characterize efficiency of technological processes in FEC and its losses during their production and delivery to the consumer.

Energy saving (energy economy) is realization of legal, organizational, scientific, production, technical and economic measures aimed at effective use and economical expenditure of FER, and at commitment of renewable energy sources in economic turnover. Activity in the field of energy saving is characterized by the indicators of actual savings of FER, decrease in FER losses; decrease in energy consumption of production [21]. Within the framework of this research, energy saving was estimated as decrease in losses of primary and produced FER while their manufacture, transformation and final use.

Energy security is a state of immunity of citizens, society, the state, economy from threats of deficiency in meeting their demands in energy with economically available energy resources of acceptable quality, from risks of break in continuity of power supply [1]. Ensuring energy security is determined by resource sufficiency, economic availability, ecological and technological acceptability. Indicators of energy security characterize:

– FER delivery reliability and their reservation;

Table 1. Indicators of energy-sufficient development

Trends	Indicators
1. Energy consumption	1. Energy density of GRP of the constituent territory of the Russian Federation, as % of basic level (kgoe / dollar). 2. Energy density of GRP of the constituent territory of the Russian Federation, as % of basic level (kWh / dollar). 3. FEC energy consumption, kgoe /dollar
2. Energy efficiency	1. Integral coefficient of energy efficiency (share of usefully implemented FER), % 2. Share of FEC in GRP, %. 3. Share of FEC in export of constituent territory of the Russian Federation, %. 4. Share of FEC in final consumption of FER, %. 5. Specific consumption of fuel on electric supply, kgoe/kWh. 6. Specific consumption of fuel on heat supply, kgoe / Gcal.
3. Energy saving	1. Specific losses of FEC, as % of FER output. 2. Electric power losses in electric networks from overall volume of electric supply, %. 3. Losses in heat networks, as % of heat production. 4. Share of FER total losses, as % of FER output.
4. Energy security	1. Ratio of volumes of production (extraction) of natural energy to gross consumption of FER, %. 2. Share of renewable energy sources in FER output, %. 3. Share of dominant type of fuel in gross consumption of FER, %. 4. Ratio of gross installed capacity of power suppliers to maximum actual load in the energy system (reserving), %. 5. Ration of FER imports to FEC output, %. 6. FER consumption per caput, kgoe/ person 7. Share of expenses of households on FER, %. 8. Ratio of household expenditures on FER to level of the cost of living, %. 9. Wear of fixed assets of FEC organizations, %. 10. Standard of stock capital accumulation in FEC, %.

Source: It is drawn up by the authors

- diversification of suppliers and types of deliverable FER;
- energy independence;
- FER economic availability for all consumers.

Energy indicators used in this project are listed in the **Table 1**.

The indicators of the energy strategy of the Russian Federation for the period until 2035 were considered while drawing up the **Table 1** [1].

FEC Model as a Part of the Region Model

The model, developed by the authors in the class of CGE-models and used for regional forecasting, was taken as a model of the Russian Federation regions [22]. The regional economy is broken into the set of economic agents by the boundaries of main partitions and classes of OKVED economic activity (Russian Classification of Economic Activities of OKVED 2). Such agents as “households”, “public authorities”, “an external environment” and “the invisible hand of the market”, which is responsible for supply-and-demand equilibrium in the markets of products, were added in the model.

Simulated economic agents produce one or several products from the basic set, which are realized in the region or are exported. At the same time, agents get necessary intermediate products (including necessary energy resources) and production factors as inside the region, and on import, taking into account resource and budgetary restrictions. The following basic set of conventional products is used in the region model: 1 - intermediate goods and services (including types of FER, used for processing, transformation and final use); 2 - investment goods and services; 3 - consumer goods and services (including types of FER, used by households); 4 - infrastructure services; 5 - state services; 6 - labor services.

Economic agents, involved in production, transformation and processing of FER, are united in the FEC model, which is presented by three sectors (**Figure 3**). In **Figure 3**, thick arrows show FER flows, thin ones – cash flows. Sectors and kinds of activity of the FEC model are listed in the **Table 2**.

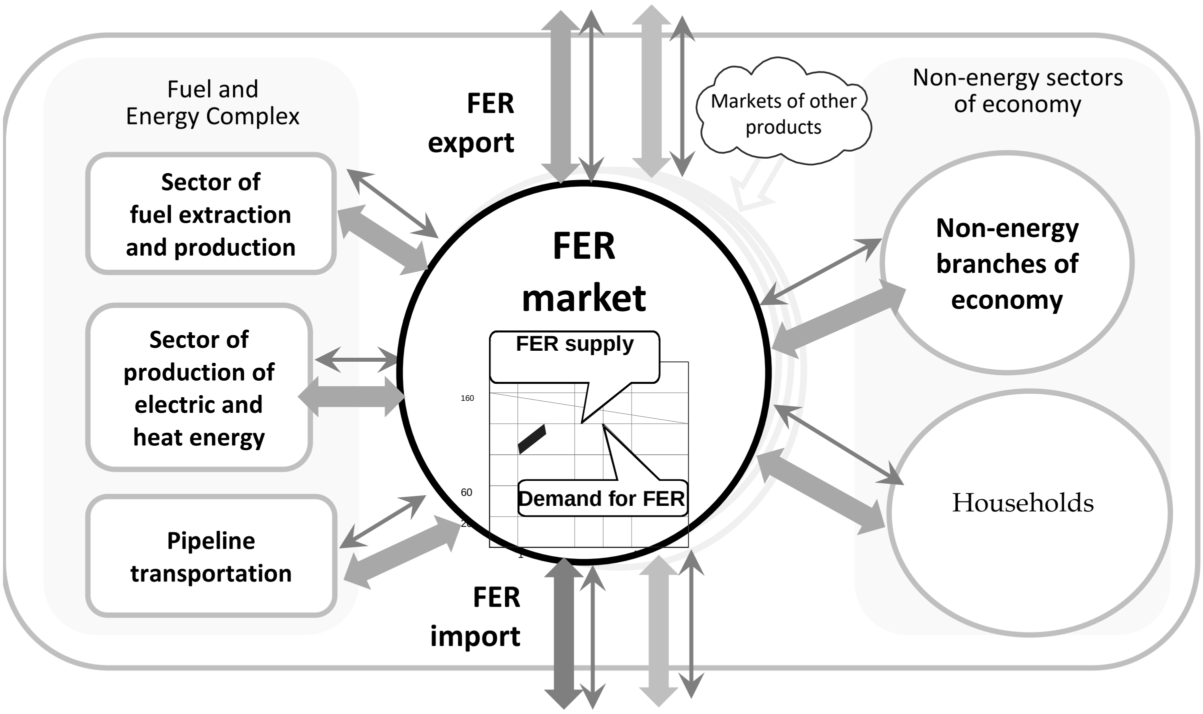

Figure 3. FEC model as an element of the regional economy model

Table 2. Sectors and types of activity of the FEC model

Sector of the FEC model	Type of activity according to OKVED
Sector of extraction and production of fuel	05. Coal mining. 06. Extraction of unrefined oil and natural gas. 09. Provision of services in the field of extraction of mineral resources. 19. Production of coke and petroleum. 35.2. Production and distribution of fuel gas.
Sector of production of electric and heat energy	35.1. Production, transmission and distribution of electricity. 35.3. Production, transmission and distribution of steam and hot water.
Pipeline transportation	49.50.1. Transportation of oil and petroleum by pipelines. 49.50.2. Transportation of gas and products of its processing by pipelines.

Source: Russian Classification of Economic Activities (OKVED 2).

In the FEC model, the following basic set of FER is used: coal, firewood, other solid fuel, oil and gas condensate, natural gas, hydraulic power, atomic energy, other natural energy resources, furnace oil, diesel fuel, automobile gasoline, gas of the oil and gas processing enterprises, dry, liquefied gas, other oil products, electric power, thermal energy.

Activity of the economic agents, who are a part of the model, is described by bidirectional generalized production functions, which, on the one hand, form the offer of agents at corresponding markets, and on the other - generate demand for intermediate products (including FER) and products, which are production factors in accordance with technological matrixes of agents. The Generalized Production Function (GPF) of the economic agent $j \in D_{BFI}$, belonging to FEC, forms the following flows of resources and money:

1 – flow of producible FER:

$$X_j^{out}(t) = \min\left\{X_j^{plan}(t), X_j^{pot}(t), X_j^{dem}(t) + \Delta X_j(t)\right\}; \tag{8}$$

2 – flow of purchased production factors:

$$X_j^d(t) = A_j(t) X_j^S(t); \tag{9}$$

3 - flow of money, received from FER realization:

$$q_j^S(t) = \left(X_j^{out}(t) - \Delta X_j(t)\right) P_j^T(t); \tag{10}$$

4 - flow of money, paid for delivery of intermediate products and production factors:

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

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

$X_j^{plan}(t)$ – the column-vector of planned FER output that is set by a scenario;

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

$X_j^{dem}(t)$ - the vector of demand for FER, produced by j agent on the part of other economic agents, including nonresidents;

$\Delta X_j(t)$ - the vector of FER stock addition, produced by j agent;

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

A_J - the technological matrix of j agent, which characterizes expenditures of intermediate products (including FER) and productive factors per unit of produced FER;

$q_j^s(t)$ - cash resources, поступающие агенту от реализации ТЭР;

$q_j^d(t)$ - cash resources, paid by an agent for acquiring of necessary intermediate products (including FER) and production factors;

$P_J(t)$ - the column-vector of prices, set by j agent, for produced FER (producer's prices);

$\hat{P}(t)$ - the column-vector of FER prices for consumers in FER market (purchasers' prices).

Potential output of j agent is calculated by the formula:

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

where B_j -a technological vector, connecting the level of FER output with values of production factors; $k_j(t)$ - overall cost of fixed funds of j agent; $l_j(t)$ - number of employed; $g_j(t)$ - growth rate of cumulative labor efficiency and agent's capital.

In the region model, the balance in the markets of conventional products, including FER markets, is provided by the grocery and sectoral balance (GSB), built within SNA-2008 [28]. In such a case, the balance relations are formed for all conventional products, used in the model, including all 15 types of FER, which were listed above. In particular, the balance of i type of FER ($i \in I_{FER}$) in natural form has the following view:

$$x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t) = x_i^{out}(t) - x_i^{exp}(t) + x_i^{imp}(t) - \Delta x_i(t) \tag{13}$$

The left part of the balance (13) shows natural demand of the regional economy for FER of i type for: transformation in electric energy and caloric $\left(x_i^{d1}\right)$, processing in other types of fuel $\left(x_i^{d2}\right)$, use as non-energy raw material $\left(x_i^{d3}\right)$; final consumption $\left(x_i^{d4}\right)$. The values x_i^{d1}, x_i^{d2} are calculated as ultimate acquisition of i type of FER by agents, included in FEC. The values x_i^{d3} and x_i^{d4} are calculated as productive consumption of i type of FER by petrochemical branches and also as aggregate final consumption of i type of FER by all agents of the economy.

The right part of the balance equation (13) shows the offer of i type of FER in the regional market: x_i^{out} - ultimate output of i type of FER in the region by FEC agents; x_i^{exp} - export of i type of FER by producers; x_i^{imp} - acquisition of i type of FER by import; Δx_i - stock changes of i type of FER.

The balance in the value form for i type of FER ($i = 1,2, \dots ,15$) will be written as follows:

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

where: $\hat{p}_i$ - an average price of i type of FER in the FER market (consumer's average price); p_i - an average price of producer of i type of FER; Δq_i - total transport and trade mark-up for i type of FER.

The Fuel and Energy Balance (13) – (14), formed within the FEC model, is a part of the general GSB. It plays the role of the "balance of balances", and that allows modelling interference of FEC and other sectors of the economy through interbalance connections.

Table 3. The format of FER private balance

Balance sheet items
1. Resources of FER *(production of FER plus import minus stock addition)*
Production (extraction) of FER
Import
Stock addition
2. Supply of FER *(resources of FER minus import)*
Resources of FER
Export
3. Total consumption of FER in the region
3.1. Transformation and processing
3.1.1. Transformation of fuel in electrical energy and caloric
including:
in a thermoelectric power station of common use
in refuse-fired plants and other sources
3.1.2. Processing in other types of fuel
3.1.3. Use of FER as raw material and on non-fuel needs
3.2. Final consumption in the region
3.2.1.Final consumption of FEC – overall total
Own consumption
including:
electric power
fuel industry
pipeline transportation
Mining and production losses
Distribution losses
3.2.2.Final consumption (without FEC),
including:
agricultural industry, hunting and silviculture
extraction of mineral resources (without FEC)
processing productions (without FEC)
....
Others
Delivery to the population

Source: it is developed by the authors

The developed model was calibrated on the statistical material of the Samara region. Calibration consisted in assignment of numeric values to exogenous parameters of the model. These values should best fit to real values of similar parameters. In particular, the parameters of technological matrixes of A_j and B_j of economic agents, coefficients of flexibility of FER expenses on output, tariffs and climatic conditions were estimated while calibrating.

While creating a summary fuel and energy balance of the constituent territory of the Russian Federation, single-product balances of FER (13) - (14) were brought into line with methodological developments of the Ministry of Energy of the Russian Federation and Rosstat, which do not essentially differ from the generally acknowledged technique of drawing the balances of IEA/Eurostat in the last documents. The used format of the single-product energy balance, built according to the scheme "supply - demand", is shown in the Table 3. The balance reflects formation of the offer of a certain type of FER and its use in processes of transformation, transfer and final consumption. In comparison with methodological developments of the Ministry of Energy of the Russian Federation [23] the following changes, which, according to the authors, raise its analytical opportunities, were made in the offered single-product balance:

- the line «2. Supply of FER (resources of FER minus export)» was added, it shows aggregate supply of the fuel and energy balance;
- the line «3. Total consumption of FER in the region» was added, it reflects total effectual demand for FER in the region;

- final consumption of FEC is emphasized in final consumption of FER in the section («3.2.1. Final consumption of FEC – overall total»), it includes own consumption on production needs and losses on extraction, production and distribution of FER;
- final consumption of FER of other sectors of the economy is showed in the section «3.2.2. Final consumption (without FEC)», where types of economic activity were showed without FEC branches.

Forecasting Technology of Balanced Development of the Economy and FEC

Forecasting on the model is based on the scenario approach, which provides convergence and iterative matching of forecasts of energy consumption and production of energy resources by the main types of FER. In the process of coordination of FER supply and demand, *the predictive FEB* plays the integrating function. It provides formation of consistent and mutually agreed system of forecasts of economic development of the region, volumes of consumption and production of main types of fuel and energy and also production capacity of FEC branches. The procedure of forecasting is organized in the form of two interconnected contours: a contour of forecasting of the regional economy and contour of FEC forecasting. The development scenario of the regional economy $U_{RE}(t)$ is expertly formed in the first contour. It contains empirical assumptions about the behavior of economic agents (expect FEC) on the forecasting horizon: a demographic scenario; expected indexes of production and deflator indexes of prices and tariffs; parameters of tax, investment and budgetary policies. Gross output, intermediate consumption and added value in the sectors of the regional economy is forecasted on the basis of the $U_{RE}(t)$ scenario. Also initial forecast of energy consumption in these sectors are calculated (left parts of FER balances) (13). As a result of these calculations the general requirements to the FER components are formulated in a natural form:

$$x_i^d(t) = x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t); i \in I_{FER}. \tag{15}$$

These needs of FER are detailed as requirements to development of production base of the corresponding FEC branches. Further, taking into account the forecast about tariffs on FER, effectual demand for FER components in the sectors of economy is estimated in monetary terms:

$$q_i^d(t) = \left(x_i^{d1}(t) + x_i^{d2}(t) + x_i^{d3}(t) + x_i^{d4}(t)\right)\hat{p}_i(t), i \in I_{FER} \tag{16}$$

and left parts of FER balances are formed (14).

According to the FEC development scenario $U_{FEC}(t)$, development of production capacities (12) for each FEC branch is forecasted in the second contour with due account for the expected forecast of investments into the fixed capital of FEC and growth of energy tariffs. The potential production of energy resources is predicted on this basis in physical units:

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

Then the potential supply of FER is formed in the regional market with consideration for liabilities of the FER regional producers for their export or outflow to other regions of the Russian Federation:

$$x_i^S(t) = x_i^{out}(t) - x_i^{exp}(t) + x_i^{imp}(t). \tag{18}$$

On the basis of (18) FER supply is calculated by reference to the forecast of tariffs on FER components in monetary terms:

$$q_i^S(t) = \left(x_i^{out}(t) - x_i^{exp}(t) - \Delta x_i(t)\right)\hat{p}_i(t) + x_i^{imp}(t)p_i(t) + \Delta q_i(t) \tag{19}$$

Right parts of FER balances (13) and (14) are formed from the components (18) and (19).

The calculated prospective demand for types of FER (15), (16) correlates element-by-element with opportunities of their supply (18) and (19). If on the forecasting horizon $t \in [t_1, t_T]$

$$\begin{Bmatrix} x_i^d(t) \le x_i^S(t) \\ q_i^d(t) \le q_i^p(t) \end{Bmatrix}, \tag{20}$$

then it means that FEC potential covers the region's need in *i* type of FER, and tariffs on FER form supply of the resource at the level of demand, providing development. Excessive supply

$$\Delta x_i(t) = x_i^p(t) - x_i^d(t) \tag{21}$$

can be eliminated owing to: increases in export of *i* type of FER; reduction of resource output; decrease in import of a resource; replacements of *i* TER of scarce resources by *i* type of FER. Decisions on correcting of the excessive supply are formed at the level of adjustment of scenario conditions of FEC development $U_{FEC}(t)$.

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

$$\begin{Bmatrix} x_i^d(t) > x_i^S(t) \\ q_i^d(t) \leq q_i^p(t) \end{Bmatrix}, \tag{22}$$

then it means that FEC potential does not cover the region's needs in *i* type of FER. It is necessary to increase the supply potential of *i* type of FER or update the economic growth, or do both things. Increase in supply potential is possible by means of increase in resource output; decrease in outflow of *i* type of FER; increase in resource import; replacement of *i* type of FER by other energy resources.

Increase in FEC potential demands quite certain resources of development, which are limited and can be easily estimated. Operations on import-export are evaluated on the model of the external environment.

Reduction of FER consumption by the economy can be reached due to correction of economic growth towards reduction and also owing to implementation of measures on energy saving, decrease in energy density of production and increase in energy efficiency of the applied technologies.

Managerial decisions on liquidation of disequilibrium between FER supply and demand are formed at the level of updating scenario conditions of development FEC $U_{FEC}(t)$ and the economy $U_{RE}(t)$ within balance equations (13), (14).

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

$$\begin{Bmatrix} x_i^d(t) \leq x_i^S(t) \\ q_i^d(t) > q_i^p(t) \end{Bmatrix}, \tag{23}$$

then it means that tariffs on *i* type of FER form resource supply at the level that does not correspond to the region's effectual demand on this *i* type of FER. It is necessary to reduce a tariff on this type of FER within the balance equations (14).

The procedure of coordination between development scenarios of FEC $U_{FEC}(t)$ and the economy $U_{RE}(t)$ is carried by stage wise iterative correction of the initial scenario (initial approximation)

$$U^0(t) = [U_{RE}^0(t), U_{FEC}^0(t)]^T, \tag{24}$$

set by PMD. The correction tools are scenario parameters, changes in which are aimed at coordination between supply and demand on all types of the used resources (including FER) within formation of the overall grocery and sectoral balance in natural and value forms [27]. The consistent development scenario of the regional economy and FEC is formed in the process of iterative matching:

$$U^*(t) = [U_{RE}^*(t), U_{FEC}^*(t)]^T. \tag{25}$$

Search Technology of Energy-Efficient Development Scenario

The purposes of energy-efficient development of the constituent territory of the Russian Federation are established in the form of targets (2) for indicators of the economic development and the chosen system of energy indicators (**Table 1**). The procedure of goal setting is an independent task that goes beyond the current article. Let us introduce a criterion F, characterizing cumulative relative deviation of the vector of indicators $E(t) = [E_{RE}(t), E_E(t)]^T = [e_1(t), e_2(t), \dots, e_N(t)]$ from the task trajectories $E^0(t) = [E_{RE}^0(t), E_E^0(t)]^T = [e_1^0(t), e_2^0(t), \dots, e_N^0(t)]^T$ in measure points $t \in [t_1, t_2, \dots, t_T]$:

$$F_E(U, t) = \left\{ \sum_{i=1}^{N} \left\{ g_i \sum_{k=1}^{T} \left| \frac{e_{E,i}(U, t_k)}{e_{E,i}^0(t_k)} - 1 \right| \right\} \right\}. \tag{26}$$

where N - a total quantity of indicators (economic and energy); g_i - weight of the i indicator; T - a number of points at the strategizing interval.

Then the task of search of the energy-efficient variant of development (3)-(6) will reduce to the following task of optimization: to find acceptable scenario of development of the regional economy and FEC $U(t)$, which will minimize general «dissatisfaction» with failure to achieve purposes, established for energy indicators in points $t = t_1, t_2, \dots, t_T$ on the strategizing horizon $[0, t_T]$:

$$\min_{U(t) \subset D_U} F_E(U(t)) = \min_{U(t) \subset D_U} \left\{ \sum_{i=1}^{N} \left\{ g_i \sum_{k=1}^{T} \left| \frac{e_{E,i}(U, t_k)}{e_{E,i}^0(t_k)} - 1 \right| \right\} \right\}. \tag{27}$$

where the indicators $e_{E,1}(U,t), e_{E,2}(U,t), \dots, e_{E,N}(U,t)$ are calculated on the region model $M_E(U,t)$ in solving the direct task of scenario forecasting and (4)-(6) and development $U(t)$, belonging to the space of managerial decisions D_U, set in the form of admissible intervals of scenario parameters regulation.

Let us submit the general scenario $U(t)$ in the form of the control matrix U with the dimension $L \times T$, where $L = m + n$ - dimension of a united vector of scenario parameters of the regional economy development $U_{RE} = [U_{RE,1}, U_{RE,2}, \dots, U_{RE,m}]^T$ and scenario parameters of FEC development$U_{FEC} = [U_{FEC,1}, U_{FEC,2}, \dots, U_{FEC,n}]^T$, and T is a number of points at the strategizing interval:

$$\mathrm{U} = \begin{bmatrix} u_{1,1} & u_{1,2} & \cdots & u_{1,T} \\ u_{2,1} & u_{2,2} & \cdots & u_{2,T} \\ \cdots & \cdots & \cdots & \cdots \\ u_{L,1} & u_{L,2} & \cdots & u_{L,T} \end{bmatrix}. \quad (28)$$

Let us denote $\mathrm{U}^{(0)}$ as initial approximation of the control matrix U (basic scenario) and submit it in the following form:

$$\mathrm{U} = \mathrm{U}^{(0)} \otimes K. \quad (29)$$

where $K = \|k_{i,j}\|_{L \times T}$ - a correcting matrix with the dimension $L \times T$;

$\otimes$ - a symbol of the element wise matrix multiplication.

The record (29) allows reducing the task (31) to the search of the efficient correcting matrix. The effective method of search of an efficient matrix K^{opt} is offered in the article [27]. It allows solving the tasks of the class (27) for many tens of the purposes N and hundreds of control variables L for acceptable time. The equation solver, developed on the basis of the matrix method, automatically forms development scenarios:

$$\mathrm{U}^{opt} = \mathrm{U}^{(0)} \otimes K^{opt} \to \begin{bmatrix} \mathrm{U}_{RE}^{opt}(t) \\ U_{FEC}^{opt}(t) \end{bmatrix}, \quad (30)$$

where values of energy indicators E_E approach to the established purposes E_E^0 as close as possible with due account for the importance of these indicators (scales g_i) and resource restrictions for the operating influences.

DISCUSSIONS

The ambiguity of conditions of energy-efficient development supposes that managerial decisions can't essentially be one-time and tough, they should be systematically reconsidered in relation to the changing conditions with the use of permanent managerial decision support systems that consider real properties of economy and the energy sector. As managerial decisions in economy and the energy sector can contradict each other, it is expedient to carry out search of the best ratios between indicators of general economic and energy efficiency within the joint task of multicriteria optimization, where along with the general economic purposes, targets of energy-efficient development are established in the form of goals for the chosen system of energy indicators. The choice of the system of energy indicators should answer the question: what development is considered as energy efficient. Weighting coefficients of energy indicators enable to place "accents of energy efficiency", correcting the solution of the general problem of search of the scenario of energy-efficient development (3)-(6) in the necessary direction. The authors worked out the system of energy indicators on the basis of legal documents. It characterizes development of FEC and the regional economy from positions of energy consumption, energy efficiency, energy saving and energy security. The advantage of the offered system of energy indicators is its completeness and consistency.

The information technology of forecasting of the balanced economic development and FEC was worked out by the authors. Within its framework, convergence and iterative matching of scenario forecasts of energy consumption and production of energy resources is provided on the basis of formation of the regional FEB. It fills in the existing gap in the market of the regional forecasting. The novelty of this methodology is that FEB, formed within the FEC model, is a part of the overall regional grocery and sectoral balance, formed for the region in general and playing the role of "the balance of balances". This allows modeling interinfluence of FEC and other sectors of economy through interbalance connections.

The methods and tools of forecasting and strategic planning of energy- efficient development of the constituent territory of the Russian Federation presented in the article are realized in the form of the predicative and analytical system, aimed at support of regional authority managerial decisions on the problems of increase in energy efficiency and energy security of the regional economy. Participation in procedures of managerial decision-making required full compliance of conceptual and information structure of model tooling to the statistics, operating in the region; and the maximum use in calculations of the regional statistical data. The model tooling was calibrated on the statistical material of the Samara region. The main problems were: incompleteness of the reported data, their inconsistency and also transition of domestic statistics to a new classification of types of economic activity in 2016

[29]. The problems of incompleteness and inconsistency of data were solved by the tooling of its supplement and balancing developed by the authors. Before official statistics emergence, the problems, connected with transition to new OKVED, were solved by modelling of absent data on new classes of economic activity.

CONCLUSION

In the article, forecasting and strategic planning of energy-efficient development of the Russian Federation region is performed through the formation of the agreed scenarios of FEC and regional economy development; which help to achieve the maximum approach to the targets for the offered system of energy indicators. This system characterizes development of the regional economy from the efficiency of production processes, transformation, distribution and final consumption of all types of FER. Search of the energy-efficient development scenario is conducted on the dynamic multisectoral FEC model, which forms interconnected production processes, processing, transportation and use of all types of fuel and energy resources in the region on the basis of formation of regional FEB in natural and cost forms. The methods and instruments of forecasting and strategic planning, described in the article, are realized in the form of the managerial decision support system of regional authorities in problems of increase in energy efficiency and energy security of the regional economy.

The received results are the basis for further research on several trends. The most important of them is deeper specification of the processes of regional energy sector forecasting and strategic planning. It can be made only by use of the developed tooling in real projects for solution of real problems with real persons, responsible for making decisions. Participation in practical tasks will allow specifying and optimizing the offered system of energy indicators, increasing adequacy of the results of modeling and forecasting. Another important trend of the research is formation of the complex assessment of energy saving potential of the regional economy for specification of targets and scenarios of energy-efficient development.

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