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TOOLS FOR SUSTAINABLE DEVELOPMENT OF REGIONAL ENERGY SYSTEMS

Nowadays, it is relevant to consider changes in the structure of the fuel and energy balance of industrial regions and the availability of imported fuel and energy resources, especially in the areas that lack energy sources. The ongoing structural shifts in energy consumption systems and the growing uncertainty in energy markets encourage the development of tools for improving the sustainable development of regional energy systems. To refine the theoretical and methodological basis of the study, we defined its conceptual framework, described the differences between sustainable functioning and development of the energy sector and determined the factors of its regional differentiation and manifestations of the energy crisis. Further, we identified the shortcomings of the existing methods for forecasting the demand for electricity. We paid special attention to quality factors of strategic planning in the region, in particular, the used statistics and documents. Based on the analysis of integrated resource planning (IRP) methodology, our experience in forecasting fuel and energy balances, assessment of sectoral indicators of energy efficiency and energy demand in the region, we proposed a model for predictive and analytical justification of regional programmes for energy development. Such a model significantly increases the information reliability of these programmes' implementation. Considering organisational tools to support sustainable development, we developed a regional energy management scheme and a mechanism stimulating local energy companies to improve energy efficiency in the consumption sector, enhance regional competition and attract investments in the renewal of fixed assets. The study has practical significance due to recommendations and tools for adjusting regional energy policy based on the coordination of the predicted parameters for various participants in the energy supply process.

Keywords: regional energy, sustainable functioning, sustainable development, energy policy, integrated resource planning, environmental and economic assessment, damage from energy production, technological modernisation, energy efficiency, forecasting, fuel and energy balance

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Introduction

The key factor in the current development of the power industry in Russian regions is the new stage in electrification [1] caused by the modernisation of the production facilities and technologies in manufacturing, agriculture, transportation, and the public utility sphere. Another important factor is the significant uncertainty regarding economic growth rates, energy demand, investment risks, and energy prices. There is evidence that in these conditions, the construction of large power generating units can lead to negative effects such as power shortages, spikes in electricity and heat prices, and non-rational energy consumption [2].

To solve the above-described problem, a more flexible model of power generation is necessary. Such a model would combine complementary system and regional contours and result in building power stations of large energy generation capacity ranging from hundreds kW to thousands MW. For further development of regional energy, it is necessary to set the optimal parameters for the development of small-scale energy generation, characterised by high investment mobility, technological, and environmental efficiency. These measures can be implemented simultaneously with the growth in energy load in a given region, ensuring the reliability of energy supply by bringing energy generation facilities closer to consumers (energy load centres).

Both contours perform their own functions. The purpose of the system contour (thermal power stations, nuclear power stations, powerful hydroelectric power stations, main transmission lines) is to maintain the stability of the national energy system and cover the maximum load of energy systems. It also plays a role in foreign energy trade.

The regional contour, which includes small-scale power stations and electrical distribution networks, performs such functions as electrification of different economic sectors, combined energy supply (heating) of territories; efficient use of local energy potential and resources, for example, natural gas and renewables; anti-crisis (stabilisation) functions such as commissioning of efficient and operation-ready power generation facilities, maintaining reliable power supply, reducing price risks for end consumers [2]. In this regard, sustainable development of the regional energy sector appears to be a pertinent task since it largely determines the overall prosperity of regions.

Conceptual background

Despite the vast body of research on sustainable development of the regional energy industry, this topic still attracts considerable scholarly attention [3–5]. For clarity, it is necessary to distinguish between the two key concepts, namely, sustainable functioning and sustainable development [6].

1. Sustainable functioning of the energy sector. This term signifies the ability of the sector to meet the needs of the national and regional economy at any given time in terms of energy supply and energy capacity by ensuring reliable and high-quality energy supply (frequency, voltage, etc.); minimising the environmental impact; keeping electricity prices acceptable for producers and affordable for consumers. Sustainable functioning means that there are limitations on the number of new power generation facilities that are being commissioned in order to provide reserve and fixed capital renovation (replacement of capital, modernisation), enhance the transmission capacity of power lines and improve the dispatch control system.

2. Sustainable development of the energy sector. This term stands for expansion (commissioning of new power generation facilities) of the energy sector to spur its economic growth and stimulate electrification through advanced energy-intensive processes. Sustainable development involves fundamental transformations of the energy sector, such as the optimisation of the power generation structure, fuel and energy balance and creation of 'green' electric plants. Sustainable development of the energy sector is both a precondition and result of economic growth.

Sustainable development is impossible without sustainable functioning of the energy sector, which is a necessary but insufficient condition. Moreover, sustainable development is based on efficient management of all types of risks caused by the uncertainty of the external environment.

In international research literature, the main discussion points regarding regional energy development are as follows:

— establishment of efficient administration and management of communication between the government, energy companies, consumers, suppliers of energy resources, financial and legal institutions (in the EU, this role is played by various committees, energy commissions, associations and coordination centres[1]);

— design of integrated markets of energy, public utility and other services, resulting in an increase in the importance of territorial network companies as integrators of the centralised electric power system and microgrids (the latter appear as a result of the application of distributed generation technologies by consumers). A separate task is the creation of special energy commissions consisting of dispatchers and suprasectoral experts to determine the nature of investment process and the optimal structure of system assets [7, 8].

planning of regional energy infrastructure development, provision of barrier-free access to this infrastructure for remote territories, including projects of the new stage of electrification [9–11];

— continuous screening of the cutting-edge energy technologies and analysis of the possibilities of their implementation with the focus on energy assets lifecycle management[2];

— minimisation of environmental impacts over the whole chain of energy production: energy generation — energy transmission and distribution — energy sale — service[3].

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[1] Dimitrova, A., Egenhofer, C. & Behrens, A. A (2016). Roadmap to Enhanced Regional Energy Policy: Cooperation in South East Europe. Retrieved from: http://aei.pitt.edu/74256/1/SR134_Roadmap_SEE.pdf (Date of access: 14.09.2019).

[2] Tillet, A., Locke, J. & Mencias, J. (2011). National Energy Policy Framework "Energy By the People … For the People". Retrieved from: https://www.iea.org/media/pams/belize/EnergyPolicyFramework.pdf (Date of access: 14.09.2019).

[3] Auth, K., Konold, M., Musolino, E. & Ochs, A. (2013). Caribbean Sustainable Energy Roadmap (C-SERMS), Phase 1 Summary and Recommendations for Policymakers. Retrieved from: http://www.worldwatch.org/system/files/nPhase%201 %20C-SERMS%20 Summary%20for%20Policymakers%20(1).pdf (Date of access: 14.09.2019).

The key institutional instrument of sustainable energy development is the regional energy policy[1], describing a set of measures tailored to the unique conditions of a given region and its energy system. In international studies, matters of regional energy policy are usually linked to energy strategies [12]: for instance, it is highlighted that the implementation of the Smart Grid strategy requires a special innovation policy to stimulate competition in energy and energy service markets, diversify pricing plans for active energy consumers, and encourage investment.

Russian literature draws on the considerable experience accumulated in this sphere, especially in the field of system energy research developed by research teams of Melentiev L.A., Makarov A.A., and Voropay N.I. from the Russian Academy of Sciences (RAS) in Moscow and Irkutsk [13, 14]. In the mid-1970s, RAS researchers in partnership with the Main Computing Centre of the State Planning Committee (Gosplan) made calculations for the optimisation of fuel balance by applying the Guidelines for optimizing the development of the fuel and energy complex [15] and the Guidelines for the use of marginal costs for fuel and electric energy [16, 17].

In post-Soviet Russia, the market economy required considerable adjustments to the methodological framework of the system energy research [14]. New instruments were proposed, such as the SCANER information modelling system [18] for devising sustainable development strategies in the energy sector. This tool can be used to simulate changes in markets for the key types of fuel and energy and obtain quantitative measurements of relative deviations, economic parameters, etc. In the system of market relations, the search for optimal decision criteria relies on commercial effectiveness [19–21].

In terms of energy research and innovation, Russian scientists have been keeping up with the world's most advanced standards. In our view, at the current stage, it is important to focus on energy demand management programmes and the documents containing guidelines and regulations for public engagement in the discussion of energy policy. The energy policy, in its turn, should determine the prospective profile and spatial development of the region. Studies should particularly focus on analysing mechanisms for electrification management at the new stage, characterised by radical changes in consumers' requirements for energy efficiency, environmental safety, reliability and sustainability of the energy sector.

Thus, the regional energy policy is expected to lay a foundation for socio-economic development by enhancing the reliability of energy supply and resource efficiency and minimising the negative impact of the sector on the environment in the current political, economic, social, technological and environmental conditions. In practice, policy implementation tools include regional energy programmes, specifying investment projects, stages, timeframes and control mechanisms [2].

Table 1 illustrates the factors that shape the energy policy depending on the economic and other characteristics of Russian regions.

We believe that the anti-crisis focus of the energy policy is of prime importance in this respect. Thus, policy should comprise a set of measures based on prior analysis of the factors and forms of energy crisis to prevent the localisation of negative effects in the regional power industry. In this case, the term energy crisis stands for the failure of the energy sector to meet the energy demand in the current conditions (including the economic growth rate, population, energy consumption structure, the efficiency of production and transportation).

The crisis can take different forms and be caused by both endogenous (in relation to the industry) or exogenous factors. Their analysis is necessary to develop a set of measures to prevent the possible negative effects (Table 2). All the above-mentioned factors may together produce a synergistic effect, which, in turn, can exacerbate the energy crisis.

Comprehensive methodology for planning and optimising energy programmes

Integrated resource planning (*IRP*) method. The integrated resource planning (*IRP*) method is based on a comprehensive approach to energy saving in production and final energy consumption, especially in areas with high potential of energy efficiency. From the economic perspective, however, the expenditures of energy companies on energy saving are considerably lower than the costs of building

[1] Dimitrova, A., Egenhofer, C. & Behrens, A. A (2016). Roadmap to Enhanced Regional Energy Policy: Cooperation in South East Europe. Retrieved from: http://aei.pitt.edu/74256/1/SR134_Roadmap_SEE.pdf (Date of access: 14.09.2019); Tools and Concepts for Local Energy Planning. Retrieved from: https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/easy_tools_and_concepts_for_local_energy_planning_en.pdf (Date of access: 14.09.2019).

Table 1

Conditions and factors influencing energy policy

Basic conditions for energy policy making	Examples of characteristics of regional energy sectors
Environmental and resource characteristics	Availability of boiler and furnace fuel, potential of renewable energy sources, climate
Structure of productive forces	Energy intensity of production; level of electrification of a region; structure of the fuel and energy balance by consumer type; share of the industrial sector in total energy consumption
Energy supply system	Structure and reserve capacity in the sectors of power generation and transportation; the depreciation of productive assets
Energy consuming industries	Provision of electricity, heat and natural gas to consumers; potential for energy efficiency enhancement; adequate levels of electrification and gasification

Table 2

Factors and various crisis phenomena in regional energy systems [2]

Endogenous factors	Forms of crisis	Exogenous factors	Forms of crisis
Increased depreciation of fixed assets	Reproductive	Non-payments	Financial
Lack of coordination in the development of the energy system	Disintegration	Inflation	Investment
Inefficient energy consumption structure	Structural	Structural shifts in the regional economy; decline in manufacturing output	Financial, investment-related
Environmental pollution	Environmental		

Table 3

Differences between traditional planning and integrated resource planning (IRP)

Characteristic	Traditional planning	*IRP*
Type of commodity/service	Electricity and heat	Power services
Power supply (resources)	Power generation facilities of energy companies	Additional factors: consumer energy saving, independent energy producers in the region
Technological policy	Mostly large bioenergy plants or nuclear power plants	Wide range of power generation systems and power supply systems
Environmental factor	Considered indirectly through the corresponding costs	Considered directly through environmental criteria
Public opinion	Seldom considered in decision-making and to a limited extent	Considered in the discussion of plans of an energy company
Uncertainty and risk	Not considered at all or considered only indirectly	Development of specific measures to reduce uncertainty and related risks
Planning models	Optimisation (deterministic) models	Imitation (probabilistic, multivariate) models

new power generation facilities or renovating old ones provided that the latter are in abundance. This difference in costs can be used to balance the interests of the key actors of the energy market.

Analysis shows that the application of the *IRP* method in practice [2, 22–24] creates a win-win situation for all stakeholder groups. Energy companies reduce their investment risks when creating capital-intensive power generation facilities. Consumers, in their turn, enjoy a more reliable high-quality energy supply, lower tariffs, and access to advanced energy efficient technologies. Energy saving measures and the use of renewables make a region more self-sufficient in terms of energy, increase the flexibility and adaptability of its energy systems, and improve the regional economy in general.

Planning with the help of the *IRP* method differs significantly from traditional planning (Table 3) and includes the following stages.

1. Goal setting.
2. Forecasting of energy and thermal loads of consumers.

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3. Analysis of the available energy balance capacity and power of the energy system within the planning horizon.

4. Resource evaluation from the perspective of energy demand considering the potential increase in energy efficiency in consumption.

5. Resource evaluation from the perspective of considering the potential increase in energy efficiency in generation.

6. Analysis of environmental impacts for each scenario of the energy system's development.

7. Risk and uncertainty analysis.

8. Selection of the plan of resource allocation[1].

9. Public evaluation of the energy system development plan.

Analysis of the energy planning system in Russia and its conformity with modern standards. Strategic planning documents of the Russian Federation[2] fit into modern international approaches in the sphere of energy development:

1. The Russian system of energy indicators corresponds to the most advanced global trends and includes such indicators as the share of renewables in the total energy consumption; share of small-scale (distributed) power generation; energy efficiency in different industries and sectors; and anthropogenic emissions [25, 26].

2. The Russian system of energy indicators considers structural shifts in the regional energy balance, placing a special emphasis on the transition to renewable energy sources.

3. Strategic planning in Russia is based on indicators of energy saving and energy efficiency enhancement as well as energy intensity of gross regional product (GRP).

4. Strategic planning documents describe the mechanism of sustainable development of the regional energy industry.

At the regional level, widely accepted modern indicators in the sphere of energy saving and energy efficiency are used: for example, energy intensity of GRP; the ratio of the costs of energy resources to GRP; indicators reflecting consumption of fuel and energy resources; indicators showing the use of renewables and secondary energy resources.

Thus, in Russia, there is a comprehensive system of industry-specific and regional strategic documents based on the most up-to-date concepts of socio-economic development. These documents include the Energy Strategy of Russia until 2030, strategies and programmes of socio-economic development of territories, all of which describe the challenges, goals and targets of regional energy development.

However, the computation of these indicators may be problematic due to some methodological difficulties and the lack of statistical data [27, 28]. For example, the Rosstat (Federal State Statistics Service) methodology for calculating energy intensity of gross domestic product (GDP)/gross regional product (GRP) is often criticised, as it does not sufficiently explain how primary energy consumption in regions is calculated. However, Rosstat started to provide data on energy intensity of GRP in prices of 2012, which can be used for comparative analysis of periods and regions.

Regression estimates of forecast dynamics of GRP in current (according to Rosstat data for 2007–2016) and comparable prices of 2007 for the Sverdlovsk region are shown in Figure 1. As only approximate values are available when converting into comparable prices of 2007, estimates of the attainability of the desired level of GRP energy intensity reduction can be distorted by 40 % for the period of 2007–2020[3].

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[1] In the USA, indicative plans are developed with the help of imitation models of 'integrated analysis of development of the region's energy system'. See: Wilson, R. & Biewald, B. (2013). Best Practices in Electric Utility Integrated Resource Planning. Examples of State Regulations and Recent Utility Plans. Retrieved from: http://www.raponline.org/wp-content/uploads/2016/05/rapsynapse-wilsonbiewald-bestpracticesinirp-2013-jun-21.pdf (Date of access: 14.09.2019).

[2] Basic Principles of the State Policy of the Russian Federation for the Period until 2025 Adopted by the Decree of the President of the Russian Federation of 16 January 2017 N 13. Retrieved from: www.pravo.gov.ru, 16.01.2017, N 0001201701160039; Federal Law of 23 November 2009 N 261-FZ. 'On Energy Saving and Improvement of Energy Efficiency", on Amendments to Specific Legislative Acts of the Russian Federation'. Adopted by the State Duma on 11 November 2009. Decree of the President of the Russian Federation of 4 June 2008. N 889 "On some measures to improve the energy and environmental efficiency of the Russian economy"; Decree of the Government of the Russian Federation of 31 December 2009. N 1225 "On the requirements for regional and municipal programs in the field of energy saving and energy efficiency".

[3] Decree of the President of the Russian Federation of 4 June 2008. N 889 "On some measures to improve the energy and environmental efficiency of the Russian economy".

Translation

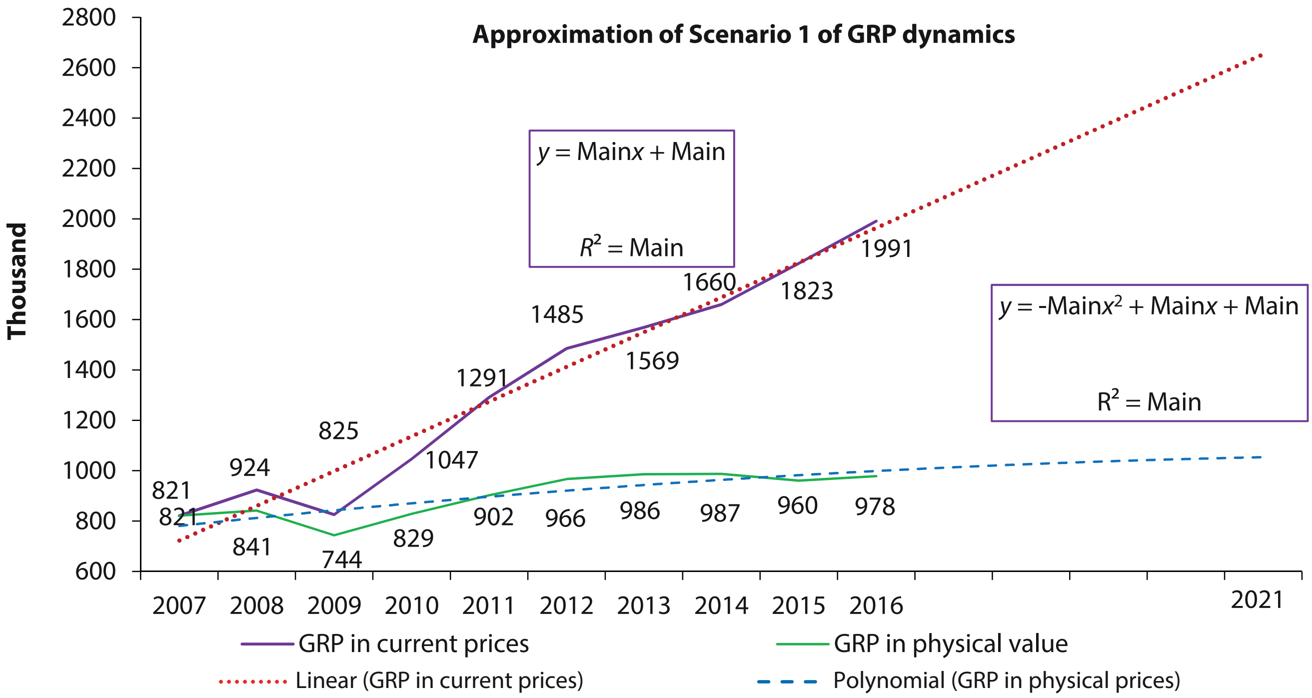

Fig. 1. *Comparison of gross regional product (GRP) dynamics of the Sverdlovsk region in current (basic) prices and in comparable prices of 2007*

Some drawbacks of the current strategic planning system of Russia decrease the efficiency of the corresponding programmes and measures. In this regard, the optimistic mid- and long-term estimates of socio-economic development raise numerous questions. What attracts attention is the absence of a pessimistic development scenario, the lack of analysis of economic trends, threats and risks, differences in the planning horizons of certain documents, limitations in the access to statistical data and the low quality of data.

Some important characteristics of regional strategic energy plans that correlate with the method and scheme of integral resource planning can be illustrated by the two main documents of the Sverdlovsk region:

1) Scheme and Programme of Development of the Regional Energy Sector (for the Sverdlovsk region for 2015–2019 and for the following period until 2024)[1] (hereinafter 'Scheme');

2) The Development of the Housing and Public Utility Sector and Energy Efficiency Improvement in the Sverdlovsk Region until 2024[2].

The main purpose of the first document is to present proposals for the development of network infrastructure and power generation facilities in the mid- and long-term periods in accordance with the demand for energy and capacity of the power systems, investment, and information support for policy-making in the energy sphere. Unfortunately, the document does not provide estimates of composite energy demand.

Most Russian regions are facing the problem of 'unreasonable' increase in the number of boiler rooms, including rooftop boilers, in zones with centralised heat supply. This, in turn, leads to the decrease in the share of combined heat and power production by power plants and is harmful to their technical and economic performance. This statement contradicts the goals of the development of distributed generation. It is necessary to optimise heat supply schemes by balancing centralised and decentralised schemes, ensuring the conformity of the length of the heat network to the effective radius of the heat supply system, and minimising heat losses. The documents also mention the loss of heat network owners' long-term interest in efficient exploitation of these networks as consumers are

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[1] Decree of the Government of Sverdlovsk Region of 21 May 2014 n 438-pp "On Approval of the Scheme and Programme of Development of the Regional Energy Sector (for the Sverdlovsk region for 2015–2019 and for the following period until 2024".

[2] Decree of the Government of the Sverdlovsk Region of 29 October 2013 N 1330-PP 'On Approval of the State Program of the Sverdlovsk Region "The Development of the Housing and Public Utility Sector and Energy Efficiency Improvement in the Sverdlovsk Region until 2024".

switching to local heat supply sources. Additionally, they lack the motivation to develop low/medium power energy sources capable of operating on local energy resources.

Although the Sverdlovsk region is one of the largest producers and consumers of energy in the country, small-scale power generation in the region still leaves much to be desired and has practically no influence on its energy system and economy. For example, in the last fifteen years, the share of all operating small-scale energy units has been less than 1 % of the capacity of the regional energy system. The main impediments to the development of small-scale power generation operating on local fuel include the high costs of extraction and large capital expenditures as well as comparatively low prices of the electricity produced by the regional energy system. The development of renewables-based small-scale energy systems depends on environmental and economic conditions of a region such as the hydrologic potential and patterns of wind power.

Nevertheless, the main goals and targets of energy development listed in this document formally include expansion of the share of small-scale power generation and the use of renewable energy sources identification of the optimal limits for the development of centralised and decentralised power supply systems, assessment of the feasibility of local energy resources in the Sverdlovsk region using a set of indicators of socio-economic, environmental, energy efficiency and energy security.

The second document "Development of the Housing and Public Utility Sector and Energy Efficiency Improvement in the Sverdlovsk Region until 2024" specifies a set of measures and time frames in sub-programmes for the development of the regional energy sector, energy saving, and improvement of energy efficiency. The proposed baselines rely on the Strategy of Socio-Economic Development of the Sverdlovsk region for 2016–2030.

In 2007–2016, the mid-term forecasts of fuel and energy balances (FEBs) were drawn up in alignment with the socio-economic development forecast[1] (for more detail on the methodology see [29]). However, there are no mentions of any possibilities of development of distributed energy systems by using local energy resources and renewables, except for the question about the feasibility and effectiveness of such systems.

Predictive-analytical support of regional energy programmes

The energy demand forecast significantly influences the parameters of the development programme for the energy sector. The forecast relies on the adjusted Long-Term Forecast for the Socio-economic Development of the Russian Federation up to 2030, devised by the Ministry of Economic Development of the Russian Federation. Our analysis shows the following main drawbacks of the energy demand forecast

1. There is no factor analysis of the retrospective sector-specific dynamics of consumption and no alternative forecasts. Moreover, there are neither references to the forecast methodology nor any estimation of its reliability.

To illustrate the reliability of the forecasted energy demand in the Sverdlovsk region, Table 4 compares the values given in the Scheme's main scenario with the actual Rosstat data (electricity balance) for 2013–2018. The revealed undervaluation of the forecasted energy demand can result in serious problems for customers.

2. Significant errors found in the forecasts for 2013, 2017 and 2018 show that the methodology of the energy demand forecast should be further improved. We believe that it would be more effective if the calculations were oriented to GDP indicators from the regional forecast of socio-economic development, the data for the sector-specific GRP structure and energy intensity data for specific types of economic activity in the retrospective period.

The reliability of the energy consumption forecast significantly depends on the quality, completeness and availability of statistical data. As we have already mentioned, energy intensity values of GDP/GRP calculated by Rosstat are quite difficult to use in regional forecasts. GRP values noted by Rosstat often do not include added value created as a result of activities in the sphere of national defence, some services in the sphere of state administration, etc. Furthermore, regional statistics do not reflect the results of international economic transactions that resident firms engage in (Rosstat explains that these indicators are estimated only at the national level).

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[1] The time lag in Rosstat's estimates of GDP/GRP and their structure for different types of economic activity is two years, which is why FEBs for the Sverdlovsk region for 2017 has not been formed yet.

Table 4

Difference between the forecasted demand for energy by the "Scheme" and the actual data for the period 2013–2018, million kWh

	2013	2014	2015	2016	2017	2018
Forecast values	44770	43717	43698	44012	44008	44055
Actual values	48504.9	45623.4	45305.6	45916.7	48037.3	48304.2
Forecast error	–3734.9	–1906.4	–1607.6	–1904	–4029.3	–4249.2
Error, %	8.3 %	4.4 %	3.7 %	4.3 %	9.2 %	9.6 %

Table 5

Comparison of energy intensity indicators based on the Federal State Statistics Service data and data on the fuel and energy balance of the Sverdlovsk region

Year		Energy intensity of regional GRP in basic prices, kilogram of oil equivalent/10 thousand roubles	Contribution to energy intensity of GRP in Russia in basic prices, kilogram of oil equivalent/10 thousand roubles	Energy consumption, tonne of oil equivalent	Energy intensity of regional GRP in prices of 2007, kilogram of oil equivalent/10 thousand roubles	Contribution to energy intensity of the physical amount of GRP in Russia, kilogram of oil equivalent/10 thousand roubles
Rosstat data	2012	263.02	7.8226759	39055546	404.18	12.58
	2013	237.86	6.8965122	37312200	378.56	11.81
	2014	211.53	5.9539770	35109818	355.86	11.00
	2015	194.54	5.4192925	35461683	369.40	11.18
FEB data	2012	265.15	7.8860724	39372059	407.45	12.69
	2013	245.87	7.1287309	38568573	391.31	12.21
	2014	211.80	5.9616200	35154888	356.32	11.01
	2015	206.98	5.7656664	37728214	393.01	11.89

The established procedure used for compiling annual FEBs for Russian regions is insufficient to provide a comprehensive analysis of sector-specific dynamics in the structure of production and consumption of fuel and energy resources, its retrospective changes and mid-term evaluations. Therefore, some regions have their own specialised FEBs, which consider peculiar conditions of these regions and reflect the contributions of different types of economic activity to GRP (in comparable prices of 2007), contributions to energy saving and energy intensity of GRP and consumption of primary energy resources in these spheres. Rosstat experts used to work together with the agency's regional offices, which provided additional information, helped resolve the contradictions in statistical forms and correct some errors.

There is no guarantee that the obtained results will coincide with those of Rosstat. Nevertheless, the resulting data, including the consolidated fuel balance for large and medium-sized enterprises, electricity balance and heat balance, energy consumption of the population, give us some idea about the sector-specific structure of the possible and available potential for energy saving and energy efficiency growth at the regional level (Table 5).

The differences in the estimates of GRP energy intensity based on the FEB data and Rosstat data in 2012–2014 do not exceed 3.4 %. A bigger difference was found for 2015, which can be explained by the imbalance inherent in the statistical form '4-FER' (fuel and energy distribution) but also by the adjustments made by Rosstat to the structure of regional GRP for 2015 and 2016, meaning that the FEB for this period should have been adjusted accordingly[1].

Problems of FEBs forecasting

The methodology of fuel and energy balance forecasting based on retrospective information about indicator dynamics in different economic sectors is considered preferable. The use of product aggregates and formation of FEBs relied on energy intensity data for specific product types, for example,

[1] We had no access to the adjusted indicators for 2015–2016.

this methodology was applied in the studies of the Energy Research Institute of the Russian Academy of Sciences. However, nowadays this approach is no longer possible due to a number of problems such as the incomparability of the structure of production for specific years in the period, its instability, and the lack or inaccessibility of statistical data. Thus, since 2007, the Institute of Energy Saving of the Sverdlovsk region, together with the Institute of Economics of the Ural Branch of the Russian Academy of Science, which provided methodological and analytical support, developed FEBs for different types of economic activity [30]. Such an approach did not contradict the methodology for compiling the Integrated Fuel and Energy Balance (IFEB)[1] and was applied by the Energy Research Institute of the Russian Academy of Sciences. However, the lack of some statistical data on the consumption of fuel and energy resources has led to the creation of other consumption aggregates, which can decrease the reliability of forecasts.

Additionally, forecasts may be less reliable due to the requirement that FEB parameters should comply with those of the forecast of regional socio-economic development. Analysis of the quality of this document for the period of 2012–2017 has shown that discrepancies between scenario values and actual values of GRP can be quite substantial, ranging from 7 % to 17 %. The methodology for energy consumption forecasting based on the parameters of energy intensity in specific economic sectors may lead to the accumulation of mistakes, which is why its results often fit into the 'what happens if...' rule.

Formally, the results of the agreement between FEB parameters and regional forecasts can be presented the following way:

$$\sum_i \overline{d}_{rit} \times g_{rit} = Y_{rt},\ i \in \overline{1, m};\ t \in \{t_1, t_4\};\ r \in R, \tag{1}$$

where i is the type of economic activity; r is the scenario; t is the scenario year; R is the set of scenarios; $\overline{d}_{rit}$ is the adjusted regression estimate for value added in comparable prices of 2007; g_{rit} is the regression estimate of energy intensity for types of economic activity; Y_{rt} is the projected total primary energy consumption;

$$S_{rt}\{\sum_i d_{rit}\} = F_{rt}(D_{rt}),\ i \in \overline{1, m};\ t \in \{t_1, t_4\};\ r \in R, \tag{2}$$

D_{rt} is regional GRP in current target prices from the forecast of socio-economic development; F_{rt} is the conversion operator of current target prices into prices of 2007; S_{rt} is the procedure of harmonisation of regression estimates with the indicators of the forecast of socio-economic development, resulting in adjusted regression estimates $\overline{d}_{rit}$.

In this situation, there are no available methods for accurate evaluation of the results. Nevertheless, it is possible to estimate the reliability of some of the indicators used in the forecast. GRP indicators specified in the forecast should be compared with the results of approximation of GRP dynamics based on the regression model. The regression equation with high accuracy shows the actual dynamics of GRP, except for the post-crisis recession in 2009–2010 (see Table 6).

Interestingly, scenario values of GRP for the forecast period (2018–2021) are also close to regression estimates. The formal criteria of quality of the regression model also show that it can be applied to estimate the reliability of scenario computations. To estimate energy intensity grit for specific types of economic activity, it is necessary to consider the prospective dynamics of energy intensity when choosing the type of regression equation. It is advisable to compare the forecast dynamics of energy intensity Y_{rt} with the similar value obtained by using retrospective time series of actual energy intensity values. Regression analysis of GRP dynamics in current prices using the retrospective database for 2007–2018 provides a high degree of approximation if a linear model is used (Figure 2 and Table 7), ensuring reliable estimates of primary energy consumption.

Support of sustainable development of the regional energy sector: organisational solutions

To ensure sustainable development of the regional energy sector, it is necessary to revise the boundaries of the Unified Energy System (UES) and move them closer to the boundaries of a large economic region. The UES should become a self-balancing system in terms of both energy capacity

[1] Decree of the Government of the Sverdlovsk region of 11.03.2008 № 171 PP "On the Procedure and Timeframe for Devising the Forecast of Socio-Economic Development of the Sverdlovsk Region".

Table 6

Compilation of the actual and forecasted GRP indicators with the regression model estimates (current prices, million roubles)

Year	GRP	Trend	Differences, %	Year	GRP	Trend	Differences, %
2007	820,792.5	717,227.7	0.87	2015	1 822 835,0	1 835 370,2	1.01
2008	923,550.8	856,995.5	0.93	2016	1 990 836,7	1 975 138,0	0.99
2009	825,267.4	996,763.3	1.21	2017	2 142 514,3	2 114 905,8	0.99
2010	1 046 600,1	1 136 531,1	1.09	2018	2 266 800,0	2 254 673,6	0.99
2011	1 291 019,1	1 276 298,9	0.99	2019	2 373 700,0	2 394 441,4	1.01
2012	1 484 879,0	1 416 066,7	0.95	2020	2 490 000,0	2 534 209,2	1.02
2013	1 568 655,2	1 555 834,5	0.99	2021	2 622 600,0	2 673 977,0	1.02
2014	1 659 783,9	1 695 602,3	1.02				

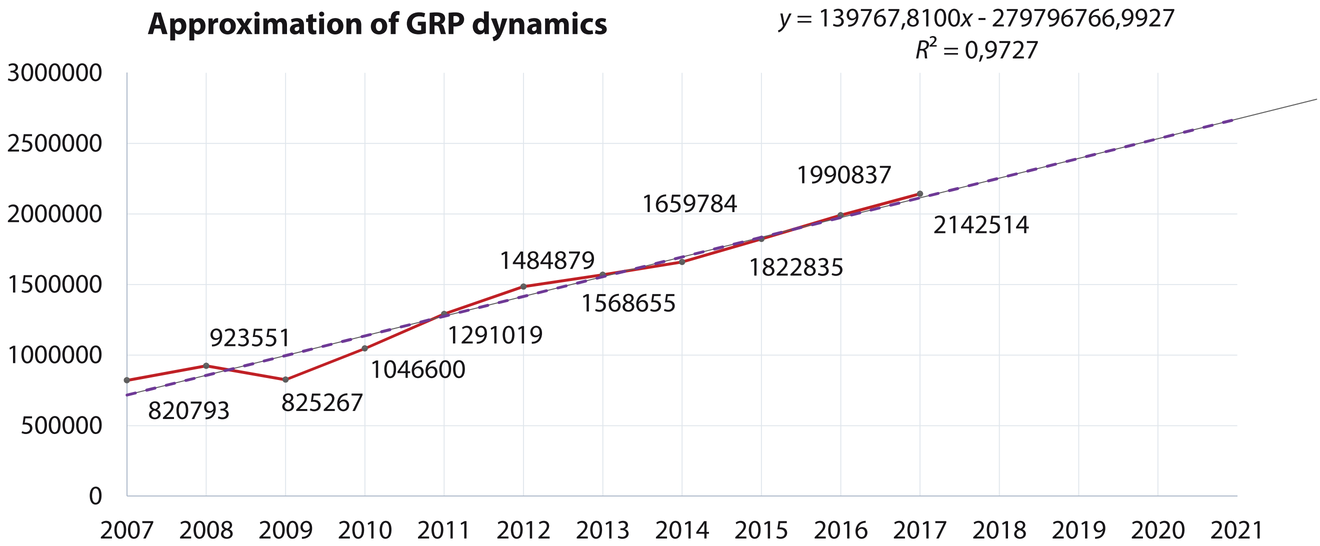

Fig. 2. *Approximation of GRP dynamics for the medium term*

Table 7

Regression quality indicators

Regression statistics	
Multiple *R*	0.986275977
R-squared	0.972740303
Adjusted *R*-squared	0.969711447
Standard error	81798.30556
Observations	11

Analysis of variance (ANOVA)

	df	*SS*	*MS*	*F*	Significance *F*
Regression	1	2,14885E+12	2,14885E+12	321.1577384	2,3852E–08
Residual	9	60218665129	6690962792		
Total	10	2,20907E+12			

	Coefficients	Standard error	t-statistic	P-value	Lower 95 %	Upper 95 %
Y-intercept	–279796767	15691934.17	–17.83061055	2,49327E–08	–315294388.3	–244299145.7
Year	139767.81	7799.162421	17.92087438	2,3852E–08	122124.8789	157410.7411

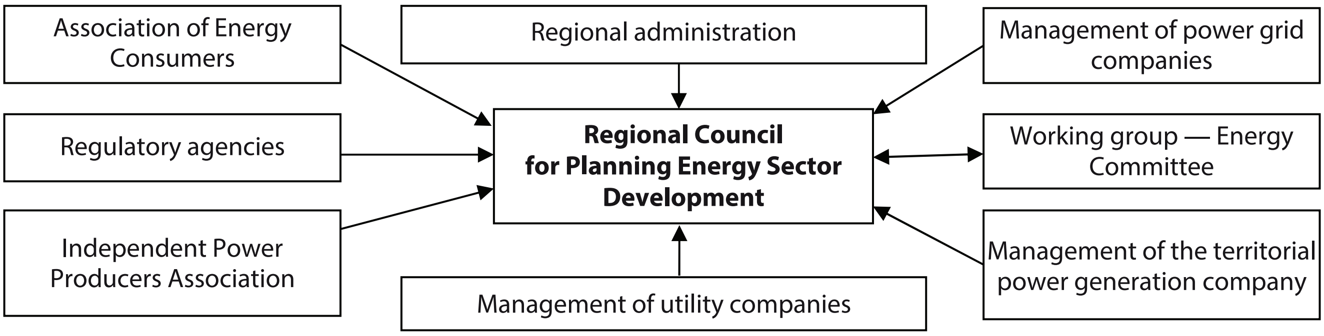

Fig. 3. *Organisation of regional energy management*

and load. The neighbouring systems should be connected by direct current transmission links with sufficient current carrying capacity. The function of these links is to provide backup power supply.

In this light, it is reasonable to identify two clusters in the regional structure of power generation: 1) large power plants serving primarily large power-consuming customers; 2) energy distributed generation units with uneven load schedules assigned to small, less energy intensive customers, for example, domestic households or customers in agriculture.

Power stations of the second cluster have to offer lower prices to their customers, thus creating conditions for minimising the power supply costs and lowering the electricity prices for all groups of consumers.

It would be reasonable to manage the regional energy sector in accordance with the scheme shown in Figure 3. At the core of the decision-making process should be the Regional Council, which develops the basic framework of the regional energy policy. The working group prepares the information and develops planning documents. Associations representing different market actors protect the interests of the latter in the Regional Council.

The motivation mechanism of the regional energy sector focuses on such priorities of the energy policy as stimulation of regional energy companies to enhance the efficiency of energy use; stimulation of competition in the regional contour; and attraction of investment to the energy sector, undergoing modernisation.

The priorities of the regional energy policy are as follows.

1. The standardisation of the parameters for new and reconstructed power stations (type of the power unit, unit capacity, type of primary energy sources, fuel efficiency coefficient, operation mode). Licencing restrictions should limit the construction of power plants with parameters different from the standard ones. Special attention should be given to the fuel efficiency coefficient and capital investment.

2. The use of tax incentives to attract investment into building power units in compliance with the normative requirements and priorities of the technical policy (the standard profit and property tax rates can be reduced to 0 % for the whole payback period)

3. Accelerated depreciation used in new advanced power units for taxation; linear or gradual depreciation of the active part of fixed assets in the short term. The increased depreciation deductions should be used for renovation and upgrading of obsolete district power stations.

4. Guarantee of product sales and acceptable return on capital for owners of renewable power plants and small-scale power plants.

5. Priority purchase right given to investors responsible for the renovation and upgrading of power stations in accordance with the technical requirements and standards. Privatisation and change of ownership under other terms should be prohibited.

6. Stimulation of energy efficiency growth and reduction of operating costs of power stations by setting the norm of the required gross proceeds (RGP) and RGP distribution method that would consider the effect of combined production in energy and heat prices.

7. Stimulation of cooperation between regional energy companies and energy and heat consumers within the framework of demand management programmes, in particular those based on the method of distributing the gains from energy efficiency improvements.

Conclusion

Our participation in developing a methodology for compiling regional FEBs and using them to assess energy demand leads us to several conclusions regarding the content and quality of regional strategic planning documents. We would also like to offer some relevant practical recommendations. It is necessary to develop efficient mechanisms for coordinating strategic planning efforts in the energy sphere at the regional level. These mechanisms include schemes and programmes for energy sector development, programmes for the development of the public utility sphere and energy saving, and methodological guidelines for mid-term forecasting of electricity demand in Russian regions. Further research is needed in the field of energy demand management and analysis of the data on greenhouse gas emissions of regional energy sectors.

Regional energy policies can be improved by including measures to increase regional self-sufficiency in this sphere, establish tariffs and energy prices that would be acceptable to energy companies and consumers (especially population and small businesses), and promote corporate environmental responsibility of energy companies. These goals should be seen as motivational milestones for the development of energy investment programmes in Russian regions, technological modernisation of energy production enterprises, formation of energy market infrastructure conducive to the active participation of consumers in load management as well as matters of energy saving and implementation of advanced energy efficient technologies.

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