Energy Supply System Development Management Mechanisms from the Standpoint of Efficient Use of Energy Resources

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Abstract. The paper discusses the problem of improving the mechanisms for managing the development of electricity and heat supply systems in regions with the aim of increasing the efficiency of energy resources use in the context of liberalization of economic relations in the energy sector. On the basis of the considered methods and the compiled system of management efficiency criteria, the structural and functional decomposition of the energy complex development management system at the territorial level was carried out. The mismatch of the power system control system was revealed, caused by the complication of the control system and the composition of the decision-makers. Improved models for managing the development of electricity and heat supply systems in the country's regions are proposed, allowing to take into account modern trends in the expansion of the use of market mechanisms for managing territorial energy and to ensure a balance of interests of management entities at various organizational levels. For their implementation, organizational mechanisms have been developed that describe the interaction of territorial government bodies and territorial generating companies in the implementation of investment programs. The proposed mechanisms for managing territorial energy allow in market conditions to fully use the production potential and incentives for the development of territorial generating companies, which creates conditions for reducing management costs and implementing the goals of state energy policy.

1. Introduction
The country's energy security is achieved by ensuring the controllability of the energy systems of its regions. In modern studies of the regional energy systems of Russia, it is noted that today there is a significant level of threat of disruption of stable energy supply in more than 75% of regions, which is associated with the dominance of one resource in the fuel and energy balance, depreciation of assets and their inability to efficiently operate in market conditions, energy waste of regional economies. In many respects, these problems of ensuring energy security are associated with the low quality of management of the development of energy systems at the territorial level, including due to the complication of the management system and the composition of decision-making entities caused by the processes of globalization and liberalization of energy.

The ongoing processes of globalization and liberalization of the energy sector lead to the complication of the management system and the composition of decision-making entities, which
increases the requirements for the manageability of regional energy systems, especially in terms of managing their development [1, 2, 3, 4].

The conflict of interests generated by the market, expressed in the difference in ideas about the efficiency of the energy economy at different levels of management, leads to a mismatch in the energy system management system [2, 5]. While the criterion of the efficiency of the power system on the part of the state is the efficiency of its operation while ensuring a given level of reliability, the criterion on the part of power companies is profitability, that is, the ability to generate income from the use of power system objects in various trading sectors of the energy markets, including using market power.

Failure to take into account the factor of inconsistency of management criteria in the formation of the energy strategy for the development of the energy complex of the region by the state and municipal authorities leads to the fact that the energy security measures outlined in the Energy strategy of Russia are not carried out at the level of energy enterprises or are unrealizable for them in the current market conditions. This creates the prerequisites not only for deviating the development of the energy complex from the scientifically grounded directions laid down in the energy strategy, but also for the formation of completely different vectors of its evolution caused by unexplored causal relationships, which creates an additional threat to energy security.

In the context of the continuing liberalization of economic relations in the energy sector and the expansion of the use of market management mechanisms, in order to fully implement the strategic priorities of the state energy policy, it is necessary to improve the management system for the development of the energy complex from the position of ensuring effective interaction of government bodies with market participants and self-regulatory organizations. An adequate reflection of the interests of the subjects of management is the basis for the formation of a system of decision-making criteria for the development and functioning of regional energy systems.

2. Literature review

At present, the energy sector is firmly connected with all spheres of the country's economic activity, and none of them can function fully without energy supply. At the same time, in various literary sources, the state's activity in the energy sector is traditionally included in its economic functions and is understood rather narrowly as the regulation of the activities of natural monopolies in the energy sector, which is a clear underestimation of the role that energy plays in the economy [6, 7, 8, 9, 10].

The activities of the state in the energy sector, first of all, should be aimed at ensuring the reliable and continuous functioning of energy systems at various organizational levels. In this case, the key mechanism of state governance at the territorial level in market conditions will be the regulation of economic relations arising in the process of functioning and development of regional energy systems.

Such a representation of the state's activities in the energy sector allows us to single out its energy function in the form of a set of economic activities aimed at ensuring the reliable functioning and sustainable development of energy systems, the formation of markets for energy resources and products and the regulation of legal relations between their participants.

The energy function of the state is carried out through a system of state bodies, among which it should be highlighted: the Ministry of Energy of Russia (general state administration in the field of energy), the Federal Antimonopoly Service (regulation of natural monopolies and prices for energy goods and services), the Federal Service for Environmental, Technological and Nuclear supervision (technological regulation in the field of industrial safety). At the territorial level, the energy function belongs to the competence of regional executive authorities, which have different names depending on the region - Regional Energy Commission, Energy and Tariffs Directorate, Ministry of Energy.

The legislative form of the energy function of the state is represented by the following regulatory legal acts: No. 35-FZ “About Power Industry”, No. 190-FZ “About Heat Supply”, No. 69-FZ “On Gas Supply”, No. 261-FZ “On Energy Saving and Increasing Energy efficiency”, No. 256-FZ “On the Safety of Objects of the Fuel and Energy Complex” [11, 12, 13, 14, 15].
Based on the analysis of these documents, the following areas of implementation of the state's energy function can be distinguished:

- ensuring the country's energy security,
- ensuring the environmental safety of energy facilities,
- provision of conditions for entrepreneurial activity in the energy sector,
- maintaining a balance of interests of energy suppliers and consumers,
- economic justification for the set price caps for energy goods and services.

The market model of energy sector management adopted in Russia requires coordination of development strategies for its facilities by the energy enterprises that manage them and government bodies in order to ensure the required level of energy security. At the regional level, this is due to the conflict of interests generated by the market, expressed in the difference in ideas about the efficiency of the energy economy of its subjects (region and energy enterprises). While the criterion of the efficiency on the part of the state is the economy of operation (the most efficient use of natural fuel and energy resources, low cost of production of energy products) while ensuring a given level of reliability, the criterion on the part of energy enterprises is profitability, that is, compliance of economic facilities with a competitive technological infrastructure that allows you to generate income in various trading sectors of the energy markets, including the use of market power tools [2, 5, 16].

Ensuring energy security in the medium and long term requires increasing the manageability of the energy systems in market conditions at the territorial level. The situation is aggravated by the fact that most of the energy facilities were commissioned during the period of the planned economy and, in principle, were not created to function in the competitive conditions of energy markets. The market conditions of functioning have significantly affected the efficiency of energy facilities, in particular, district heating systems that provide integrated energy supply to regional consumers.

Partially, an increase in the manageability of the territorial energy economy is achieved due to the ongoing processes of combining energy assets, the creation and development of vertically integrated enterprises that enhance the influence of the state in the energy sector. On the one hand, this leads to the implementation of large-scale investment programs and a decrease in transaction costs, on the other hand, it reduces competition in the industry, and as a result, hinders the innovative development of the energy complex. [1, 2, 17, 18, 19, 20].

It is necessary to approach the consideration of the issue of ensuring the manageability (sustainable development) of regional energy systems from two sides:

- changes in market rules for the operation of power systems in order to improve the efficiency of the existing production structure,
- optimization of the production structure for the existing market rules for the operation of the economy, including through the introduction of new technologies that increase the efficiency of operating the production facilities of the power system in market conditions.

The model for managing the energy complex at the territorial level should be based on the coordination of the goals of the structural and technological modernization of the territorial energy system on the part of the state and energy enterprises, which makes it possible to achieve the necessary level of energy security of the territorial entity.

3. Background

3.1. Analysis of the power supply system management model at the regional level

The management of the power supply system at the regional level is based on the developed scheme and program for the development of the electric power industry in the region for the long term. For this, the following regulatory documents are used:

- documents of territorial planning in the field of energy,
- rules for technological connection of consumers,
- regional program of energy saving and energy efficiency improvement,
methodological recommendations for the development of a scheme and program for the development of the electric power industry for a 5-year period.

The initial information for the development of a scheme and program for the development of the electric power industry in the region are [2, 21, 22, 23]:

- forecast of demand for electricity,
- information on applications for technological connection,
- the scheme and program for the development of the unified energy system of the country, as well as reports on its functioning by the system operator.

The scheme and program for the development of the electric power industry in the region makes it possible to form an investment program for the development of regional power facilities. Fig. 1 shows a model for managing the development of the power supply system at the territorial level, drawn up on the basis of the existing procedure for developing a scheme and program for the long-term development of the electric power industry in the region [1, 2, 23, 24, 25].

**Figure 1.** Model for managing the development of the power supply system based on the existing procedure for developing a scheme and program of the electric power industry in the region.

The presented management model is characterized by the following disadvantages, leading to a decrease in the quality of schemes and programs for the future development of the electric power industry in the regions:

- there is no consideration of strategies and programs for innovative development of territorial generating companies, which leads to a discrepancy between the program and objective trends in the development of the industry in market conditions, and further causes a mismatch in the management of the power supply system at the territorial level,
- there is no consideration of the prospective development of heat supply systems associated with operating modes with power supply systems in the organization of consumers integrated energy supply,
- there are no calculations and justifying documents confirming deviations in the forecast of the level of electricity consumption, as well as proposals for the construction of power facilities by the territorial management body,
- there is no specialized control over the compliance of the developed scheme and program for the development of the electric power industry with methodological recommendations.
3.2. Analysis of the heat supply system management model at the regional level

In contrast to the management of the power supply system, the management of the development of the heat supply system is practically fully implemented at the regional level. Moreover, there are three main types of heat supply control systems [26, 27, 28, 29]:

- on the basis of administrative management, when the heat supply organization is subordinate to the regional administration,
- on the basis of a concession agreement, when the property of a municipal heat supply company is transferred to trust management; at the same time, the administration retains property rights, but it does not participate in the management of the heat supply organization,
- on the basis of private management, when the heat supply organization is privately owned (in particular, by the territorial generating company).

A generalized model of a heat supply management system is shown in Fig. 2.

![Generalized model of the regional heat supply management system](image)

**Figure 2.** Generalized model of the regional heat supply management system.

The territorial executive authority performs the functions of regulating the activities of heat supply enterprises on the basis of the Federal Law "On Heat Supply", including local natural monopolies in heat supply. Regulation is carried out in terms of marginal pricing and technological supervision. To perform the first function, a regional energy commission is formed, which sets the maximum tariff for thermal energy. At the same time, the sale and services for the transfer of heat energy (activities of heat producers and heat network organizations) are regulated within the allocated heat supply price zone. To perform the second function, territorial supervisory bodies are involved, which form the requirements for the reliability of heat supply systems.

The territorial executive body also has the function of managing the development of the heat supply system in accordance with the following principles [26, 30, 31]:

- meeting the demand for heat energy while organizing reliable heat supply in the most economical way,
- ensuring the balance of heat power and load, taking into account redundancy,
- application of territorial planning documents, including schemes of the planned location of heat supply facilities.

The administration of the municipality performs the functions of managing municipal heat supply organizations. The main management criterion is budget efficiency while providing affordable heat to consumers. At the same time, the administration often also represents consumers, exercising direct management of budgetary organizations and enterprises that operate the housing stock. Forming the tariff for heat energy, it actually determines the cost of heat for its own consumption. Therefore, the tariff for heat of municipal heat supply organizations will almost always be lower than that established...
by the regional energy commission [26, 28, 32]. In turn, this affects the underfunding, reduced reliability of the heat supply system and the quality of consumers heat supply.

Opposite in terms of the management criterion of municipal heat supply organizations are private heat supply organizations, whose task is to ensure the wealth of owners, the indicator of which is the return on equity. This management criterion assumes an increase in the price of heat while reducing the cost of producing and selling heat. Hence, this management model contributes to an increase in added value through the implementation of measures to improve the quality of energy supply to consumers and the introduction of new technologies that allow implementing energy saving and energy efficiency programs. At the same time, the cost of heat will be higher than that of municipal heat supply organizations, but in general, the reliability and quality of heat supply to consumers increases. This management model becomes relevant only when the heat market is functioning with a free pricing mechanism.

An intermediate management option is its implementation on the basis of a public-private partnership mechanism, which implies the conclusion of a concession agreement between the administration of the municipality and an entrepreneur. Under the agreement, the management of the heat supply organization is transferred to a private person who attracts investments to address the issues of technological modernization of fixed assets and improve the quality of heat supply in order to make a profit. At the same time, the municipality retains property rights. In this case, the management criterion, on the one hand, is the return on investment, and on the other, the attraction of private investment to improve the reliability and efficiency of heat supply. The multi-component nature of the management criterion leads to the need to balance the interests of the state and business.

A significant drawback of management based on concession agreements is the lack of economic incentives for an entrepreneur to channel profits into the capitalization of municipal property. Thus, most of the profits are spent on increasing private property, while municipal property does not actually develop. Only as much funds will be allocated to it as is required to operate the equipment and ensure the required return on investment [26, 30, 33, 34].

Heat supply management is also influenced by heat consumers, with whom heat supply organizations conclude heat supply contracts. At the same time, in centralized heat supply systems, the main consumer is the housing stock. Thus, the interaction of end consumers with heat supply organizations is carried out through the management company operating the housing stock, which has no economic interest in energy saving. Thus, the interests of the consumer as a buyer in the heat market are actually not represented, and the requirements for the quality of heat supply are measured by the number of complaints.

4. Methods
To improve the management model for the development of the power system at the territorial level, it is necessary to carry out a functional and component decomposition of the organization of management of its production subsystems - heat and power supply systems.

The control system of a complex object can be represented as a set of elements that form a hierarchical structure of closed loops of movement and transformation of information, implementing a control strategy that allows to ensure the compliance of the decisions made to achieve the goal [35, 36, 37, 38]. The structure of the control system describes the totality of its elements and the existing stable links between them. The organization of the elements determines the consistency of their interaction, and the functional connections between them determine the order of subordination in the process of implementing the management function.

At the moment, there is no established methodology for conducting research on management systems. In general, the study of the management system on models can be presented as Fig. 3.

The management system is considered from two positions: its current state and the one in which it should be in the future in order to ensure the controllability of the controlled object. For a model description of the current state of the control system, methods are used that allow it to formalize and identify possible control mismatches at various levels. The result of formalization is a theoretical
model of the control system, including a description of the scheme and control functions at the level of elements and subsystems. A criterion of the effectiveness of the management system is formed, from the position of which it is reorganized in order to improve the quality of management under the given scenario conditions. Thus, a model of the future management system is formed, which provides the necessary level of controllability in conditions of limited resources.

Management objectives can be identified through performance indicators that characterize the progress of the goal achievement process and describe the compliance of the results with the planned ones. The presence of deviations is the basis for making adjustments to the management system.

Performance criteria reflect the goals of management, the rational organization and functioning of the management system, the quality of its behavior and development potential. The system of management efficiency criteria is presented in Table 1 [38, 39, 40].

The number of management levels and the degree of centralization of the system can be used as indicators of the rationality of the structure of the management system. Of particular importance is the assessment of the compliance of the organizational structure of the management system with the object of management, which requires an analysis of the balance of the composition of management functions and management objectives, as well as the consistency of performance indicators.

The quality of organizational behavior can be assessed through indicators that characterize the content and organization of the management process, such as productivity and efficiency. Performance describes the result achieved by the management system per unit of time. Efficiency refers to the relative costs of operating a management system.

The indicators of the potential of the management system are adaptability, controllability and stability. Adaptability characterizes the ability of the management system to change its state for the effective performance of the control function when the operating conditions change. Controllability describes the ability of a system to respond appropriately to management influences within a time frame. Sustainability is understood as the ability of the management system to ensure compliance of the achieved results with the set goal under the influence of environmental factors.
### Table 1. Effectiveness criteria of the management system.

| Efficiency factors | Management quality characteristic | Description of the management efficiency criterion |
|--------------------|----------------------------------|--------------------------------------------------|
| Achievement of the management goal | Productivity | Compliance of the results with the management objectives |
| Providing reliable management structure | Efficiency | Balancing the composition of management functions and management objectives |
| Quality assurance of the organization of management process | Economy | The accelerated growth of efficiency of functioning of the control object compared with an increase in management costs |
| Potential for the development of the management system | Performance | Timeliness of the management system response to environmental challenges |
| Manageability | Adaptability | Operativeness and completeness of the reaction of the control object to management influences |
| Sustainability | | Stability of the management system over a long period of time |

For the model study of the management system various methods and research principles are used. The most widespread methods are: diagnostics, analysis, forecasting and synthesis (see Fig. 4).

![Figure 4. Methods of conducting research of the management system.](image)

The interrelation of methods for researching management systems presented in the Figure 4 formed the basis of the methodology for improving management systems for electricity and heat supply at the territorial level. It is proposed to use external and internal audit of the regional energy system management organization as tools for assessing the quality of management rationalization.

5. Results and discussions
Fig. 5 shows the improved management model of the power supply system.
Improving the quality of management will be facilitated by the mechanism of forming a coordinating management body, which allows coordinating management at various organizational levels between territorial executive authorities and territorial generating enterprises, adequately reflecting the interests of management entities, both in the field of electricity supply and heat supply. Also, its creation will allow:

- carry out joint planning for the development of heat and power supply systems,
- to ensure the development of an integrated energy supply to the region based on economical combined heat and power production,
- improve the quality of development programs of energy supply systems through the allocation of specialized design organizations.

The power supply system development program is the basis for the development of investment programs. The scheme of interaction between the generating company and the executive authorities within the framework of the formation of the generation development scheme at the territorial level is shown in Fig. 6.
In the presented scheme, the generating company interacts with the federal governing body bypassing the regional one, which is due to the fact that it is often a representative of the wholesale electricity market operating within the unified energy system of the country, the development of which is under the jurisdiction of the federal government level. At the same time, the improvement of the management model for the development of the power supply system requires a change in the scheme of interaction of management subjects (see Fig. 7).

![Figure 7](image)

**Figure 7.** Scheme of interaction of management entities within the framework of an improved development management model of power supply system.

The scheme of interaction of management subjects is transformed into a multilevel model of hierarchical management. The role of territorial generating companies in planning energy systems is increasing significantly.

The combination of the approaches of central planning and market competition leads to the scheme for the implementation of investment programs of generating companies, presented in Fig. 8.

![Figure 8](image)

**Figure 8.** Scheme of implementation of investment programs of generating companies based on central planning and market competition.

Unlike the management of the power supply system, management of the development of the heat supply system is implemented at the regional level. An improved model for managing the heat supply system is shown in Fig. 9.
At the moment, the development of heat supply management systems in the regions of Russia is moving towards the centralization of management and the creation of unified heat supply organizations. Moreover, they are formed on the basis of a heating network organization or a large heat source (mainly CHP) [166, 305]. But this does not solve a number of the above-mentioned management problems, among which the problem of representing the economic interests of end users in the heat market should be highlighted. This management problem can be solved by organizing a single heat supply organization on the basis of a management company that operates the housing stock.

The creation of a heat supply organization on the basis of a management company involves the implementation of the following measures:

- corporatization of the management company at the expense of the owners of residential premises and the administration of the municipality,
- transferring to the management company the function of managing the heat supply system, as well as determining the criteria for selecting heat suppliers, distributing them to base and peak,
- transfer of the function of long-term planning of the heat supply system development to the management company,
- assignment to the management company the interaction function with consumers on the issues of concluding heat supply contracts.

It is also assumed that heating network organizations will be under municipal management or operate on the basis of concession agreements, when property rights remain with the administration. In this case, the management company can also be a concessionaire and perform the functions of managing the heating network. This is especially advisable when there is a natural monopoly in the field of heat transport. With such an organization of management, the heating network company plays the role of a service that ensures the maintenance of the heat transport system in good condition.

It is advisable to separate heat sources into separate enterprises and carry out their corporatization, which will lead to an improvement in the heat supply management system through the development of competition between producers in the heat market. Accordingly, access to heating networks should be organized on the same terms. This mechanism makes it possible to solve the problem of loading their own heat sources by heat supply companies operating heating networks, despite the possibility of loading the most economical ones.

Consumers realize their economic interests through corporatisation of the management company, which represents them in the heat market. Thus, a market buyer is formed, interested in reducing heat...
consumption. At the same time, only one management company bears responsibility to consumers, which also allows improving the quality of management.

The territorial executive body regulates the activities of heat producers and heating grid companies, both on the basis of setting the maximum tariff and technological supervision. At the same time, the function of regulating the maximum sales markup under the heat supply agreement concluded by the management company with the end user is also added. As a mechanism for managing the development of the heat supply system, the developed scheme and program for the development of heat supply are used, drawn up on the basis of an energy strategy, territorial planning documents and proposals of the management company. The drawn up program for the development of the heat supply system will be the basis for the formation of investment programs for a unified heat supply organization and heat producers.

The presented developments form the management development mechanisms of the region energy system on the basis of current market and government tools for managing heat and power supply systems. The carried out improvements in the management structure of the region power system make it possible to increase the power system controllability and energy resource consumption efficiency.

6. Conclusion
In the context of the ongoing liberalization of economic relations in the energy sector, in order to implement the strategic priorities of the state energy policy, it is necessary to improve the management mechanisms of the energy complex from the position of ensuring effective interaction of government bodies with self-regulating energy enterprises. An adequate reflection of their interests should be the basis for making decisions on the development of energy systems at the regional level.

The efficiency criteria of the state and energy companies are inconsistent in the direction of the formation of the added value of products. If the state, representing the interests of consumers, is interested in reducing it, then enterprises, ensuring the profitability of production, on the contrary, in increasing it. For this, strategies of market power and artificially high production costs can be applied.

On the basis of the considered methods, a structural analysis and decomposition of existing regional management systems for power and heat supply is carried out.

For power supply management systems, a number of organizational mechanisms have been proposed to improve the quality of management. One of the proposals is the creation of a coordinating management body that allows coordinating management between territorial authorities and energy companies and carrying out joint planning for the development of heat and power supply systems.

For heat supply control systems, an organizational mechanism for the formation of unified heat supply organization on the basis of a management company that concludes direct heat supply contracts with consumers is proposed. It is assumed that the heating network organizations will be under municipal management or operate on the basis of concession agreements (with the management company), and heat sources will be separated into distinct enterprises and their corporatization will be carried out. The heat supply organization on the basis of the management company carries out the functions of heat supply management and determines the criteria for selecting heat suppliers. Consumers pursue their economic interests through corporatization of the management company. Thus, a market buyer is formed, interested in reducing heat consumption. At the same time, only one management company bears responsibility to consumers, which also allows improving the quality of management.

The proposed mechanisms for managing territorial energy allow in market conditions to fully use the production potential and incentives for the development of territorial energy enterprises, which will be a driver for reducing management costs and implementing the goals of state energy policy.

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