Multi-level Modeling of Optimal Development and Pricing in the Gas Industry

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***Abstract* — This paper studies hierarchical modeling of the optimal development of facilities of multilevel gas supply systems (GSSs), given the general issues of their aggregation and contributes corresponding development and pricing models. The models for the comprehensive development of GSSs are considered at three hierarchical levels: 1) structure optimization and investment processes; 2) optimization of seasonal gas consumption, reliability analysis and synthesis; 3) optimization of parameters of a facility with its reliability factored in, as illustrated by the main gas pipeline. Three pricing models are proposed: determination of retail prices and tariffs for natural gas for certain categories and groups of consumers; determination of wholesale gas price components for federal subjects of Russia; determination of supply and demand equilibrium between natural gas suppliers and consumers. The development and pricing models were put to test to calculate the optimal volume of gas production and transportation taking into account seasonality of consumption and reliability of GSSs equipment performance, as well as to set natural gas prices for federal subjects of Russia.**

***Index Terms* — multi-level modeling, gas supply system, mathematical models, optimal development, pricing issues.**

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I. Notation

1. Network flow model

x_{ij}, y_{ij} – gas flows through existing and new arcs.
d_{ij}, g_{ij} – throughput capacity and increments of arcs.
c_{ij}, k_{ij} – "prices" of gas transportation through existing and new arcs.
λ_{ij} — the arc coefficient that takes into account the changes in gas flow as it passes through the arc. s and t – additional nodes — the shared source and outlet.
U – the set of all nodes. v and w – total flows from node s to node t.

2. Model for selecting the areas of investment activities

x_i — the share of the total cost of implementation of the ith investment option (X_i = [0;1]).
U_i — sources of financing
$K_{i,t}$ — the value of the investment in the ith option that is made within the tth segment of the investment period.
T — the number of intervals within the investment period.
B_t — the planned amount of financial resources available within the tth interval.
$f_{j,t,i}$ — total costs of the jth production factor used as part of the ith option (e.g. wages C_{wag}, fixed assets C_{fix}, construction costs C_{con}, transportation costs C_{tr}, etc.).
$F_{j,t}$ — the capacity of the j production factor within the tth interval.
$Q_{i,t}$ — volume of gas supply to consumers as per the ith option within the tth time interval.
Qt_{min} — the minimum required volume of gas supply to consumers within the tth interval.
N — the total number of feasible investment project options.
AC_i — the average cost of the ith investment option.
BP_{pri} — the amount of budget receipts for the ith option at the beginning of the investment period.
TR_{pri}, TC_{pri} — discounted receipts and payments, respectively.

3. Model for determining the structure of financing sources

M — the number of possible financing sources.
$ACY_{j,t}$- specific costs related to the use of the jth source.
$Y_{j,t}$ — sources of financing (own funds, funds received due to the issuance of securities and other funds raised, borrowed funds).
G_t — the amount of government subsidies within the *t*th interval.
ka — the coefficient capturing the recommended ratio of own funds to other sources.

4. Model for selecting partners

$TCSpr_k$ *TCSpr* — discounted costs associated with the use of construction company services.
S_k — the set of construction companies.
$PS_{k,t}$ — the capacity of the k the construction company within the *t*th interval.
$QS_{i,t}$ — the required scope of construction work as per the *i*th option within the *t*th time interval.
X_i^0 — the share of the ith investment option in the optimal solution of the first model.

5. Model for regulating the seasonal irregularity in gas consumption

$x^P_{i\tau}, x^T_{i\tau}, x^{-T}_{i\tau}, x^x_{i\tau}, x^U_{i\tau}, x^b_{i\tau}$ — variables of interest for each node i of the calculation scheme and for each season of year τ $\left(\tau = \overline{1,T}\right)$, respectively, reflecting the volume of gas production at the fields, the volume of gas supply to the node and gas output from the node to other nodes through the MGP, the volume of gas storage in underground gas storage facilities, the volume of gas substitution by other fuels and the volume of gas use by buffer consumers.
$z_{i\tau}$ — a dummy variable in node i in time period τ that shows possible misalignment of fuel resources and demand.
L — the number of consumer categories that accept substitution of gas by some other fuel $\left(l = \overline{1,L}\right)$.
$b_{i\tau}$ – gas demand of node i that is mandatory to meet within time period τ.
$a^P_{i\tau}, a^T_{i\tau}, a^x_{i\tau}, a^U_{i\tau l}, a^b_{i\tau}$ — coefficients indicating for each node i within time period τ, respectively, process indicators (losses due to unreliability, gas consumption for auxiliaries, overconsumption of other fuel types when using them to substitute gas, etc.) for the above listed facilities.
$d^P_{i\tau}, d^T_{i\tau}, d^x_{i\tau}, d^U_{i\tau}, d^b_{i\tau}$ — constraints on the production capacity of gas fields, main gas pipelines, underground gas storage facilities, possible maximum volume of gas substitution by other fuels by various consumer categories, respectively. $c^P_{i\tau}, c^T_{i\tau}, c^x_{i\tau}, c^U_{i\tau l}, c^b_{i\tau}$ — discounted levelized cost of gas production, transportation, and storage, consumption of other fuels by consumers of category l and gas buffer units, respectively.
$u_{i\tau}$ — discounted specific damage as shown by individual nodes of the calculation scheme due to possible shortages of energy resources.

6. Model for reliability assessment of the gas supply system

$i \in R$ – nodes in the model network that correspond to the fields $i \in R_1$ consumers $i \in R_2$ underground storage facilities $i \in R_3$ junction points of pipelines $i \in R_4$.
$(i, j) \in U$ – edges connecting nodes *i* and *j*.

For each calculated field node $i \in R$ we specify:
$q^o\left[x^o\right]$ – variation series of potential gas supply to the system.
x_i^o, X_i^o – current and maximum possible gas supply from fields to the system, t.c.e.
C_i^o –specific costs of gas production, RUR/t.c.e.
λ_i^o – the coefficient that captures gas consumption for auxiliaries, $\lambda_i^o < 1$
For each calculated consumer node $i \in R_2$ we set:
$M[x_i^I], \sigma[x_i^I]$ – demand by household consumers for gas, represented by a mean value and mean square deviation of the normal law of distribution, t.c.e.
$x_i^I X_i^I$ – current and maximum possible demand for gas for consumer category I (households), t.c.e.
$X_i^{II(III)}$ – demand for gas for consumer category II (III) (industrial consumers, gas–fired boilers, and electric power plants), t.c.e.
C_1, C_2, and C_3 – specific gas cost for consumer categories I, II, III, respectively, $C_1 << C_2 << C_3$, RUR/t.c.e.
x_{0i}, B_i – current and maximum volume of backup fuel, t.c.e.
C_{0i} – specific costs of backup fuel, RUR/t.c.e.
x_i^d – total gas shortage for all consumer node categories, t.c.e.
y_{0i} – specific damage due to gas undersupply, RUR/t.c.e.
$q^{st}[x_i^+], q^{st}[x_i^-]$ – variation series of potential gas withdrawal from the UGS to the system or potential gas injection into the UGS.
x_i^+, x_i^- – potential gas supply from the UGS to the system or gas injection into the UGS, t.c.e.
C_i^+, C_i^- – specific costs of gas withdrawal or injection, RUR/tce.
V_i – storage capacity, t.c.e.
S_i – gas reserve at the beginning of the considered period, t.c.e.
λ_i^+ – the coefficient that captures gas storage losses, $\lambda_i^+ < 1$.
For each main gas pipeline we $(i, j) \in U$ set:
$q^{gp}\left[x_{ij}\right]$ – variation series of capacity.
x_{ij} – main gas pipeline capacity, t.c.e.
C_{ij} – specific costs of gas transportation from node i to node *j*, RUR/tce.
λ_{ij} – the coefficient that captures gas transportation losses, $\lambda_{ij} < 1$.

7. The model for synthesis of reliability of a complex gas supply system

(i, j) – the arcs connecting the nodes *i* and *j*.
x_{ij} – the capacity flow of the graph arc reflecting a source or transportation facility with available redundancy.
y_{ij} – the flow of additional redundant capacity of the graph arc reflecting a source or transportation facility.
z_j – the backup fuel volume.
c_{ij} – the specific cost value with available redundancy of a gas source or transportation facility.
k_{ij} – the specific value of additional redundant cost of a gas source or transportation facility.
P_j – the specific value of redundant fuel cost.
λ_{ij} – the factor that takes into account gas consumption for

auxiliaries and losses due to unreliability.
π_{ij} – the graph arc reliability factor with additional redundant capacity factored in.
α_j – the fuel supply reliability factor.
Q – the total value of gas produced by all its sources.
B – the total value of gas used by all consumers.

II. Introduction

The Unified Gas Supply System of Russia is a unique large-size system that has no equal in the world. The issues of multilevel modeling of its optimal development were reflected in [1, 2], including the works carried out at the ESI SB RAS [2-4]. To a certain extent, hierarchical modeling issues are also dealt in the research published abroad [5-17]. Various problems of making global and national projections of gas supply systems (GSS) development (generally, gas flow models are used) are solved along with those of the interaction of gas markets, and each problem is solved at its own hierarchical level. For example, the world energy models [5-7] study the interrelationships between the industries of the energy sector, including the gas industry. In global gas models [8-14] each country is treated as a standalone gas market. European market models [15, 16] make projections of natural gas production, transportation, consumption, and prices in European markets. National gas models investigate in more detail the gas markets of a particular country as is illustrated in [17]. Gas flows, demand, production, gas prices, required new capacity additions for gas transportation corridors and gas liquefaction plants are projected for different time frames. Data exchange can take place between individual models of different hierarchical levels.

The analysis of models when substantiating the development of the gas industry indicates the necessity of considering it at different hierarchical levels for improving, clarifying, and detailing the use of information base. Therefore, research in the field of multi-level modeling of the gas industry development and pricing issues is a critical task.

The object of the study is the gas industry, which includes gas supply systems that provide consumers with hydrocarbon gases, the most important raw material resource for obtaining chemical products and environmentally friendly energy.

Natural gas is produced by gas producing companies that have their main and auxiliary equipment. This gas is transported by gas transportation companies (main gas pipelines (MGP), including line pipes (LP), and compressor stations (CS)) to gas distribution systems (GDS). Then natural gas is delivered by gas distribution systems to consumer facilities (industry, energy, utilities, transport, households). The great bulk of natural gas is exported. The listed gas production and transportation facilities are complex systems that interact with each other within a single process and time cycle. They are equipped with control, regulation, and metering instruments.

Liquefied natural gas is produced in Russia by two companies (Sakhalin-2, Yamal-LNG), where natural gas is liquefied, stored, and delivered to consumers by water by dedicated tankers (gas carriers).

Hierarchical modeling of optimal development of multi-level gas supply systems is considered in this study while taking into account general issues of utilities systems aggregation, namely: mathematical models of their development, investment models, models for reliability analysis and synthesis, optimization of parameters of facilities with reliability factored in; covered are principles of pricing and methods of calculation of wholesale prices and their components for natural gas as applied to federal subjects of Russia, as well as the model for finding the supply and demand equilibrium between gas suppliers and consumers.

III. General issues of aggregation of gas supply systems companies

The subject of the study of companies producing and transporting gas to consumers is the modeling of their technical and economic performance indicators (constraints on capacity, operating costs, and coefficients reflecting the consumption of gas for auxiliaries and leakages due to unreliability).

The aggregation of the calculation scheme is understood as modeling of the actual scheme of gas supply in a consolidated form [18]. Such a scheme should reflect the actual scheme with certain accuracy while maintaining its required properties. The resulting aggregate scheme is characterized by a smaller number of nodes and links, which facilitates the analysis of results to develop the necessary solutions and use the information for calculations in mathematical models.

The Gas Supply System (GSS) is represented as an oriented graph and treated as a set of three subsystems (companies): gas sources, main transportation networks, and consumers. Source facilities include all companies that supply gas to the main transportation network: comprehensive gas treatment plants, gas chemical facilities, and underground gas storage facilities, if a given time coincides with the withdrawal period the facility operates with. Main transportation network companies consist of sections of main gas pipelines that include line pipes and compressor stations located thereon. Consumption facilities include groups of consumers that take gas from main gas pipelines and underground gas storage facilities, if a given moment coincides with the period of gas injection into a UGS.

Consumption nodes are aggregated according to the administrative and geographic principle, with federal subjects of Russia acting as consumers.

For each subject, we identify a node with the maximum demand; in case the subject has two or more nodes with the same maximum demand, the node closest to the branching node with the maximum number of adjacent nodes is selected. The demand for natural gas of an aggregate consumer is determined provided the same demand in the original and aggregate schemes.

For each federal subject of Russia we identify the CS that has gas pipelines with maximum aggregate throughput capacity passing through it. In this case, it is its aggregate consumer node.

If the CS does not coincide with the aggregate consumer node, it is denoted in the scheme as a branching node. Such a node is required to correctly reflect the main gas flows in the scheme. There is no demand for gas defined at the branching node. The entire demand of the subject is concentrated at the consumer node.

A gas production company (GPC) is denoted as an aggregate source node associated with the consumer node of the subject of the aggregate network in which the company is located. Gas production in the aggregate subject is the total production by all fields.

Multi-line MGPs are presented as single-line ones. The aggregate arc of the graph between two nodes is characterized by the total throughput capacity of gas pipelines on the border between two subjects and the length of all MGPs coming from one node to another.

To determine the aggregate technical and economic performance indicators of each arc and node of the aggregate calculation scheme, we use statistical data made available by Gazprom PJSC along with the input technical and economic data on existing GPCs and GTCs. The cost of gas production at each field, as well as the tariff for its transportation through a certain gas pipeline, are calculated taking into account the costs of the corresponding gas production and transportation company and the profit required for its internal needs.

The final operation to form a calculation scheme is to "glue" all the aggregate schemes into a single one. "Gluing" is carried out along the borders of gas transportation companies. Thus, the complex multi-line Unified Gas Supply System (UGSS) (see Figure 1) is presented in the form of an aggregate calculation scheme (see Figure 2), (different lines of the scheme delimit the boundaries within which individual gas transportation companies operate).

The aggregate existing GSS scheme is superimposed by existing large-scale projects of gas transportation systems that are at the design or project implementation stage. In addition to this, the calculation scheme is supplemented with links that characterize the projects and scientific developments, as broken down by year of the planned periods, contributed by research and design organizations. Thus, a redundant aggregate calculation scheme is built reflecting the stages of GSS development for the investigated time frame.

The obtained calculation schemes allow studying rational growth rates and proportions in development of the gas supply of individual regions and the country as a

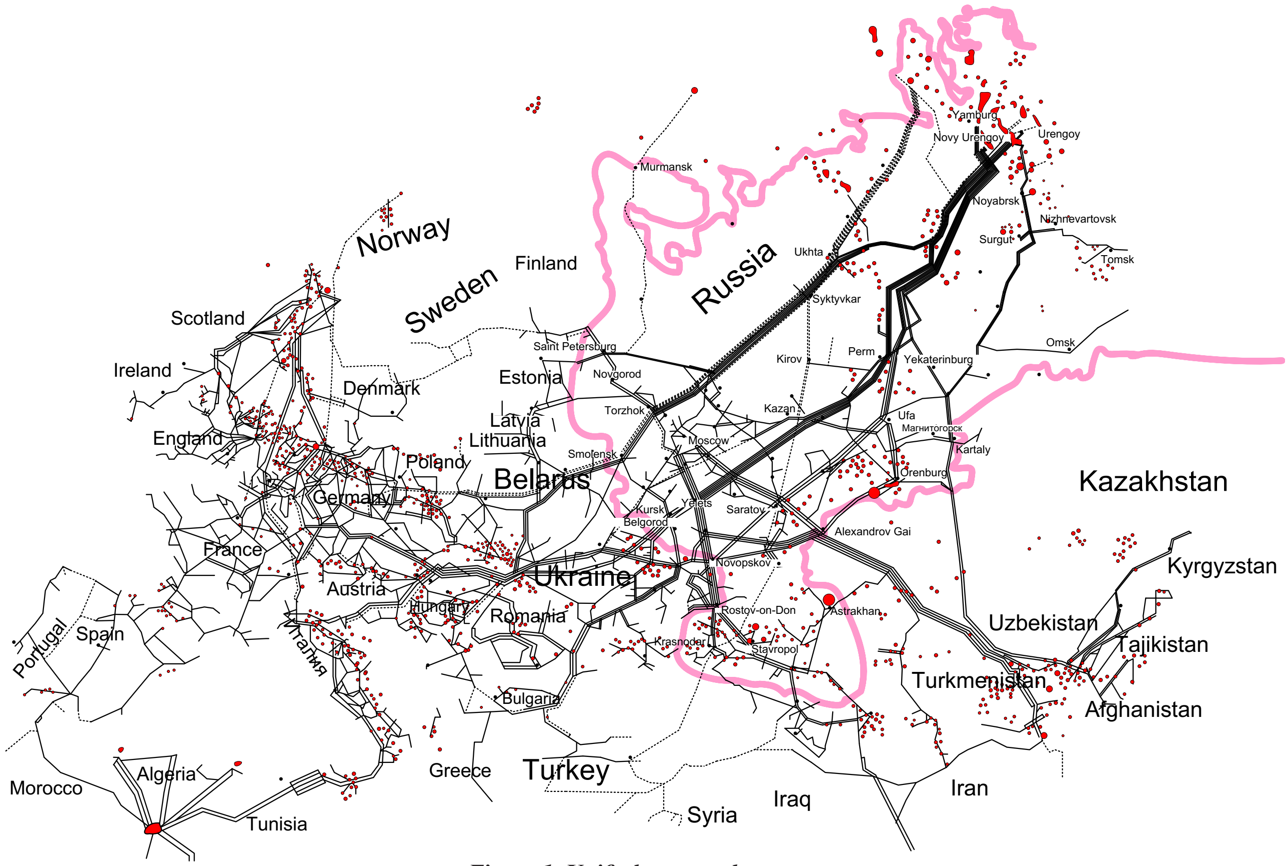

Figure 1. Unified gas supply system

whole taking into account interaction of all industries that are part of the energy sector, while touching upon general energy, economic, environmental, and other cross-industry issues.

Based on the data available in [19] an information base for multi-level modeling of development of gas supply systems in Russia to 2030 was built [4]. It captures the following: demand for gas at the nodes of the scheme, upper limits on production and transportation, as well as costs and coefficients showing gas consumption for auxiliaries and leakage flows. The database includes the following: estimation of natural gas demand dynamics in the Russian Federation and its export deliveries (the current state and prospects of gas supply markets development in federal subjects of Russia); technical and economic performance indicators for existing and new gas producing companies and gas transportation systems.

The subject of the research is the problems of prospective development of complex gas supply systems. The methodological developments that were made allow setting and solving complex problems so as to pursue the following two directions [4]: that of optimal prospective development of gas supply systems and that of pricing for gas supply systems development.

IV. Complex problems of optimal prospective development

Figure 3 shows the models developed at the ESI SB RAS to solve the problems of optimal development of gas supply systems and their interaction at the three levels of their study [4].

1. Integrated development models of GSSs of the first hierarchical level

Model for structural optimization of the gas supply system

This network flow model allows finding a gas supply plan that ensures minimum costs for gas production, transportation, and delivery to consumers when gas demand is fixed.

The generalized task of flow modeling is written down in the following form:

$$\sum_{i,j}\left(c_{ij}x_{ij}+k_{ij}y_{ij}\right)\to\min$$

$$\sum_i \lambda_{ij}x_{ij}-\sum_i x_{ij} = \begin{cases}-v, & j=s\\ 0, & j\neq s,t\\ w, & j=t\end{cases}$$

$$l_{ij}\le x_{ij}\le d_{ij}+y_{ij},(i,j)\in U$$

$$0\le y_{ij}\le g_{ij}\left(i,j\right)\in U.$$

Here, the optimality criterion is the minimum cost of gas production, transportation, and delivery to consumers, while the constraints are production capacity of existing and new companies and requirements to meet the minimum demand by consumers, provided that the balance of gas supply and withdrawal at the network nodes is maintained.

This problem of the minimum cost flow, which belongs to the class of LP problems, is solved by the modified Busacker-Gowen algorithm [1].

Based on the data from the information base built, calculations were made showing the optimal volume of gas

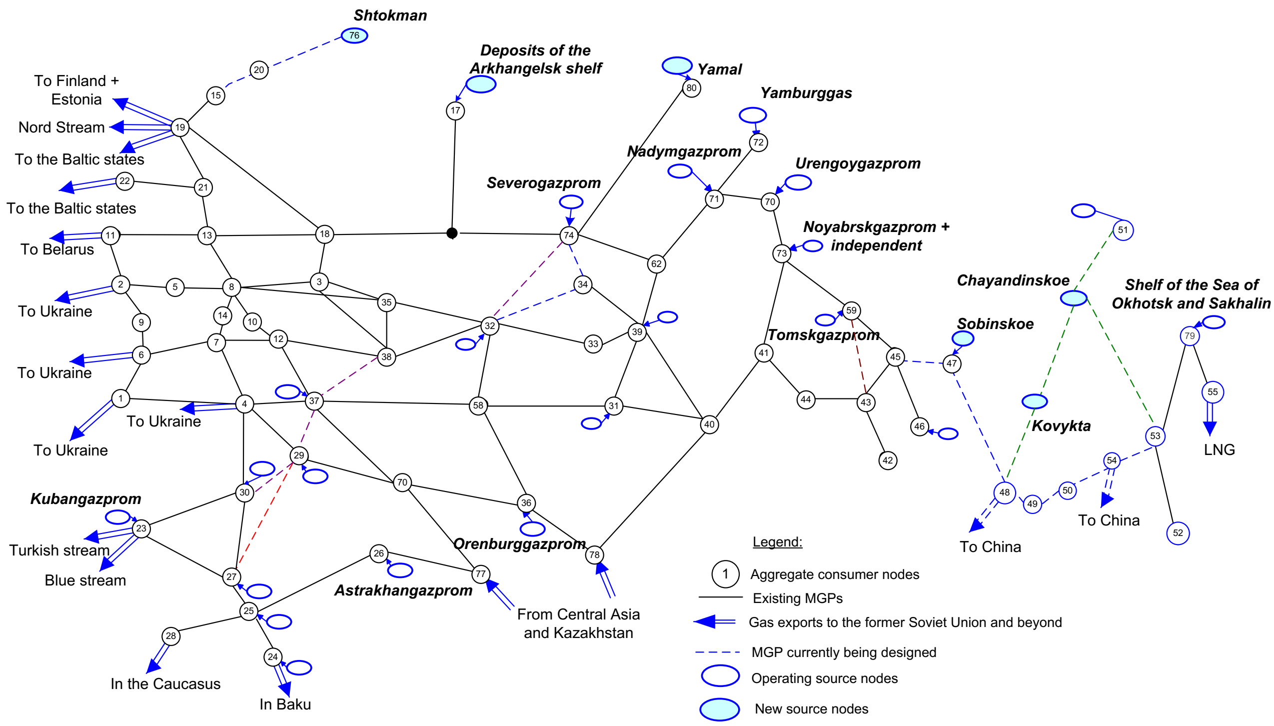

Figure 2. Redundant aggregate calculation scheme of the GSS of the Russian Federation

production and transportation for the averaged scenario of consumption in Russia and exports in years 2020, 2025, and 2030. The calculation result for 2030 is presented in Figure 4 that shows the optimal volume of gas production by gas producing companies and the volume of gas flows through the aggregate gas transportation companies.

As a result of generalization of model calculations for optimization of development of gas supply systems in Russia to 2030 [20], interval estimates of indicators descriptive of gas consumption, exports, consumption for auxiliaries, and leakages were obtained

The dotted line in Figure 4 outlines the scheme of gas supply to the Northwestern Federal District. Using this scheme as an example, in what follows we will show the details of the solutions of the models of problems of lower levels of consideration.

Models of investment processes

These models enable one to plan investments (areas of investment, their volume, and terms of their financing) in such a way that the resulting discounted effect would best satisfy the interests of all subjects [21].

The above can be presented as the following three problems: 1) choice of areas of investment activity; 2) determination of the structure of financing sources; 3) choice of partners (construction and other companies).

The mathematical model for the problem of choosing the areas of investment is as follows:

Criteria: $\sum_{i=1}^{N}[U_i \cdot x_i] \to \min,$

$$\sum_{i=1}^{N}[AC_i \cdot x_i] \to \min,$$

$$\sum_{i=1}^{N}[BPpr_i \cdot x_i] \to \max,$$

Constraints:

$$\sum_{i=1}^{N} K_{it} \cdot x_i \le B_t \left(t = 1,2,\ldots,T\right),$$

$$\sum_{i=1}^{N} f_{j,t,i} \cdot x_i \le F_{j,t} \left(j = 1, 2,\ldots, J \; t = 1,2,\ldots, T\right)$$

$$\sum_{i=1}^{N} Q_{it} \cdot x_i \ge Q_{\min_t}, \left(t = 1,2,\ldots,T\right),$$

$$x_i - x_j \le 0 \text{ при } x_i, x_j = 1 \cup 0, i \ne j \quad \left(i, j = 1,2,\ldots,N\right),$$

$$x_i + x_j \le 1 \text{ при } x_i, x_j = 1 \cup 0, i \ne j \quad \left(i, j = 1,2,\ldots,N\right),$$

$$0 \le x_i \le 1 \text{ или } x_i = 0 \cup 1.$$

It is a multi-criterion problem. The criteria show the minimum average costs and are used when the interests of the state and the national economy as a whole are reflected in the model, maximize budget receipts, and represent the interests of the state and the government, and indicate the maximum profit for the owners.

The constraints show the total financing capability; the capacity of financial resources and the conditions of gas supply to consumers.

The desired solution is a matrix that represents the amount of funding by a source of funding for each interval of the investment period.

The problem of determining the structure of financing sources for the gas supply system can be formulated as follows:

Criterion: $\sum_{j=1}^{M}\sum_{t=1}^{T}\left[ACY_{j,t} \cdot y_{j,t} / (1+r)^t\right] \to \min$

Constraints: $\sum_{j=1}^{M} y_{j,t} \ge K_t - G_t \, (t = 1,2,\ldots,T),$

$$\sum_{j=1}^{M}\left[ACY_{j,t} \cdot y_{j,t} + y_{j,t}\right] \le B_t \; (t = 1,2,\ldots,T),$$

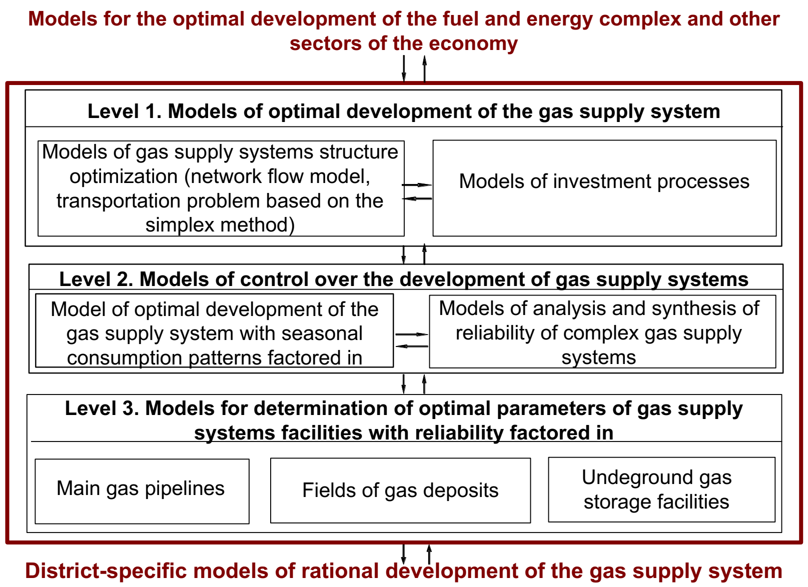

Figure 3. Models for solving problems of optimal development of gas supply systems.

$$\left[\sum_{j=1}^{M1} y_{j,t} / \sum_{j=M1+1}^{M} y_{j,t}\right] \ge ka\left(t=1,2,...,T\right),$$

$$y_{j,t} \ge 0\left(j=1,2,...,J, t=1,2,...T\right).$$

Constraints show the possibility of financing sources, as well as the coverage of investments and costs by the budget of the company.

The problem statement for the problem of choosing partners, with the latter being construction and other companies, is as follows:

Criterion: $\left[\sum_{k=1}^{K} TCSpr_k \cdot s_k\right] \to \min$

Constraints: $\sum_{k=1}^{K} s_k \cdot ps_{k,t} \ge \sum_{i-1}^{N} qs_{i,t} \cdot X_i^0 (t=1,2,...,T),$

$$s_k = 0 \cup 1 \quad (k=1,2,...,K)$$

Within this problem, out of the available set of partners, one s chooses s^0 those that ensure minimum discounted costs associated with the choice of the kth construction company.

The constraint shows that capacity of the chosen construction company should be not less than it is required as per the investment plan.

The industry average rate of return for construction is used as the discount rate to arrive at the present values of indicators, with the discounting period corresponding to the construction period.

This problem can be extended to cover suppliers providing construction (production) services for the object of investment. In addition, the problem can be modified so as to distribute the utilization of capacity of construction companies and other partners over time.

As a case study, we consider the choice of the optimal investment option for the development of the gas sup-ply system of the Russian Federation. Let us consider three options: Option one. Gazprom PJSC is developing in line with the recommendations set out in the energy strategy of Russia. Option two. The first option is supplement-ed by accelerated development of new gas production companies and construction of gas transportation systems in Eastern Siberia and the Far East. Option three. The second option is supplemented by accelerated development of new gas production companies in the shelf of the Barents and Kara Seas. Our studies provide evidence (see Figure 5) that the second option of development will be the optimal one if the development of gas supply systems in Russia will be carried out by Gazprom PJSC. The option has the lowest average costs for the minimum scenario and the highest discounted profit

2. Models of integrated development models of the GSSs of the second hierarchical level

Model of regulation of seasonal irregularity in gas consumption patterns

The model is a system of linear equations and inequalities that coherently describe the processes of gas

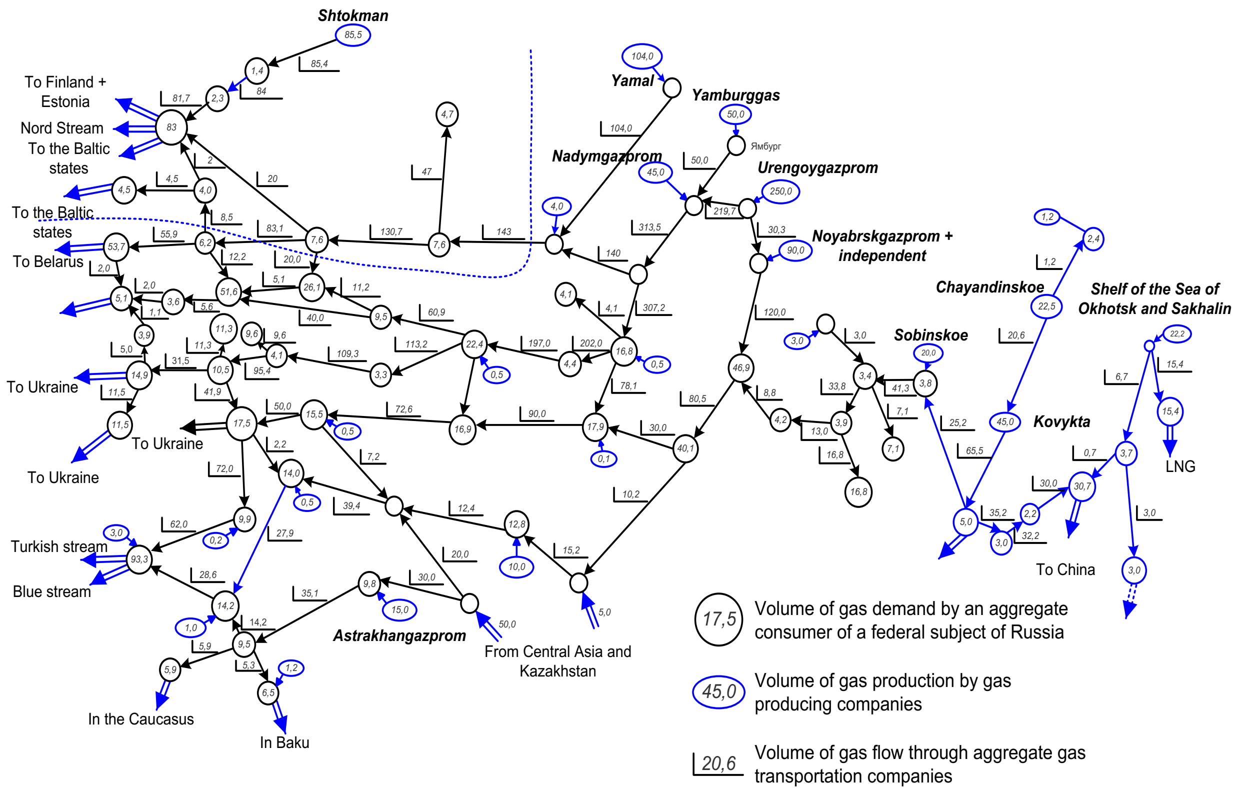

Figure 4. Optimal gas production and transportation volume for the averaged scenario of consumption in the Russian Federation and exports in 2030, bcm/year.

production, transportation, storage, and consumption by seasons of the year is as follows:

$$\sum_{i=1}^{n}\sum_{\tau=1}^{T}(c_{i\tau}^{P}x_{i\tau}^{P}+c_{i\tau}^{T}x_{i\tau}^{T}+c_{i\tau}^{x}x_{i\tau}^{x}+$$

$$\sum_{l=1}^{L}c_{i\tau l}^{U}x_{i\tau l}^{U}+c_{i\tau}^{b}x_{i\tau}^{b}+u_{i\tau}z_{i\tau})\rightarrow \min;$$

$$\sum_{\tau=1}^{T}(a_{i\tau}^{P}x_{i\tau}^{P}+a_{i\tau}^{T}x_{i\tau}^{T}+a_{i\tau}^{x}x_{i\tau}^{x}+$$

$$\sum_{l=1}^{L}a_{i\tau l}^{U}x_{i\tau l}^{U}+z_{i\tau})=\sum_{\tau=1}^{T}(x_{i\tau}^{-T}+a_{i\tau}^{b}x_{i\tau}^{b}+b_{i\tau}),$$

$$0\le a_{i\tau}^{P}x_{i\tau}^{P}\le d_{i\tau}^{P};0\le a_{i\tau}^{T}x_{i\tau}^{T}\le d_{i\tau}^{T};$$

$$0\le a_{i\tau}^{x}x_{i\tau}^{x}\le d_{i\tau}^{x};0\le a_{i\tau}^{U}x_{i\tau}^{U}\le d_{i\tau}^{U}$$

The model can take into account constraints on limited resources: fuel oil (d^f), coal (d^c), total capital in-vestment (k) and metal (M).

$$0\le\sum_{i=1}^{n}\sum_{\tau=1}^{T}\sum_{l=1}^{L}a_{i\tau l}^{U}x_{i\tau l}^{U}\le d^{f};$$

$$0\le\sum_{i=1}^{n}\sum_{\tau=1}^{T}(\sum_{l=1}^{L}a_{i\tau l}^{U}x_{i\tau l}^{U}+a_{i\tau l}^{b}x_{i\tau l}^{b})\le d^{c};$$

$$0\le\sum_{i=1}^{n}\sum_{\tau=1}^{T}(k_{i\tau}^{P}x_{i\tau}^{P}+k_{i\tau}^{T}x_{i\tau}^{T}+k_{i\tau}^{x}x_{i\tau}^{x}+$$

$$\sum_{l=1}^{L}k_{i\tau l}^{U}x_{i\tau l}^{U}+k_{i\tau l}^{b}x_{i\tau l}^{b})\le k;$$

$$0\le\sum_{i=1}^{n}\sum_{\tau=1}^{T}\mu_{i\tau}x_{i\tau}^{T}\le M,$$

The criterion is the minimized function of costs of gas production, transportation, storage and use; the following expression is a condition of equality to preserve gas production, transportation, storage and consumption flow; it is followed by constraints on gas flows, capital expenditures, and metal inputs.

As a result of solving this problem, the capacity of fields, gas transportation companies, and underground gas storage facilities is determined by standard methods of linear programming as applied by seasons of the year.

The detailed scheme of gas supply to the Northwestern Federal District in 2030 was calculated based on the model of seasonal irregularity regulation (see Figure 6). It shows the justified volume of transported gas and gas consumption for auxiliaries in winter and summer, the volume of gas storage and utilization of underground gas storage facilities as well as the volume of peak fuel utilization.

3. Models for analysis and synthesis of reliability of complex gas supply systems companies

Reliability analysis models for existing GSS facilities. The facilities include the gas main pipeline, the field, and the underground gas storage facility.

The calculation scheme of a complex multi-line MGP consists of several branches. Each branch is a chain of serially connected links, line pipes of different diameters and compressor stations with gas pumping units (GPUs) of various standard sizes.

The calculation scheme of the gas field represents a number of clusters. A cluster is understood as a parallel connected set of wells with associated equipment, as well as a separator and flow lines. A head field station is defined as a set of parallel connected elements that are, in general, heterogeneous aggregates.

Underground gas storage (UGS) facilities are typically established in depleted gas and oil field, porous aquifers, and salt deposits. Underground storage facilities in aquifers and salt layers are artificially created gas deposits.

The main process links of UGS facilities include the following: wells, connecting pipelines, and near well-bore area structures, gas treatment and drying devices, compressor stations.

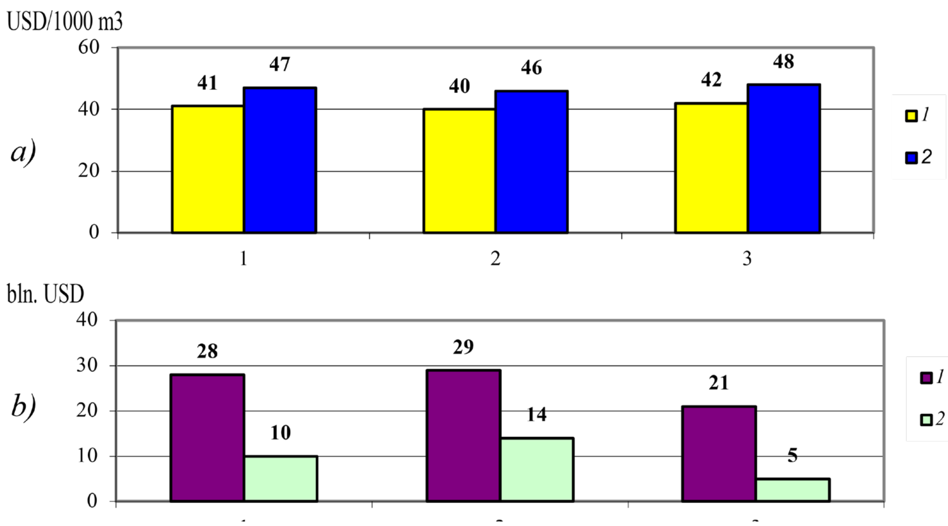

Figure 5. The problem of choosing areas of investment. ***Average costs (a) and net discounted profit (b) by options of gas supply system development in Russia. Scenario: 1 — maximum, 2 — minimum.***

The reliability analysis of the indicated facilities (MGP, field, UGS) is performed as follows:

1. Initial links (line pipe, CSs, well clusters), consisting, in general, of heterogeneous elements are replaced by a system consisting of homogeneous elements by way of reduction to equivalents;
2. probability distribution functions of the working condition are defined for these links, to this end we use the analytical method at the level of random (Markov) processes, i.e. the Death-Birth process that allows covering various types of deposits;
3. as per a predefined rule, taking into account a parallel and serial connection, the composition of distribution functions of the working condition of a given facility is performed;
4. as a result the following indicators of the facility are determined: a series of the probability distribution of its working condition; a function of the probability distribution of its working condition; mathematical expectation, dispersion, and standard deviation of throughput capacity of the facility within the considered time interval and a number of other indicators. The reliability factor is also determined for the MGP.

The reliability analysis model of a complex gas supply system is an estimation model. The object of the study is a multi-node gas supply system that is treated as a set of nodes, covering gas fields and other sources of gas, underground gas storage facilities and gas consumption nodes (with categories of consumers indicated), connected to the system of gas main pipelines and including both existing facilities and available options of their development.

The purpose of the problem of estimating the reliability of functioning of a complex gas supply system is to determine if each consumer's demand for gas can be satisfied given available (or planned) capacity, redundancy, and backup supplies.

In terms of its content, the model allows to determine the following based on gas demand and gas supply to the system from the fields as presented in a probabilistic form, as well as gas withdrawal to the system or injection into underground gas storage facilities and taking into account UGS reserves, as well as taking into account the throughput capacity of gas main pipelines, also stated in the probabilistic form, and taking into account losses of gas for auxiliaries at the fields, during its UGS storage and its transportation through the MGP, as well as the inter-changeability of fuels: key reliability indicators by individual gas supply system nodes, namely: reliability of gas supply as a probability of meeting the predefined demand, mathematical expectation of undersupply of gas and the coefficient of meeting the gas demand of consumers; depending on the ratio of obtained and set reliability of meeting gas demand by each calculated consumption node — various measures that facilitate its reduction or increase.

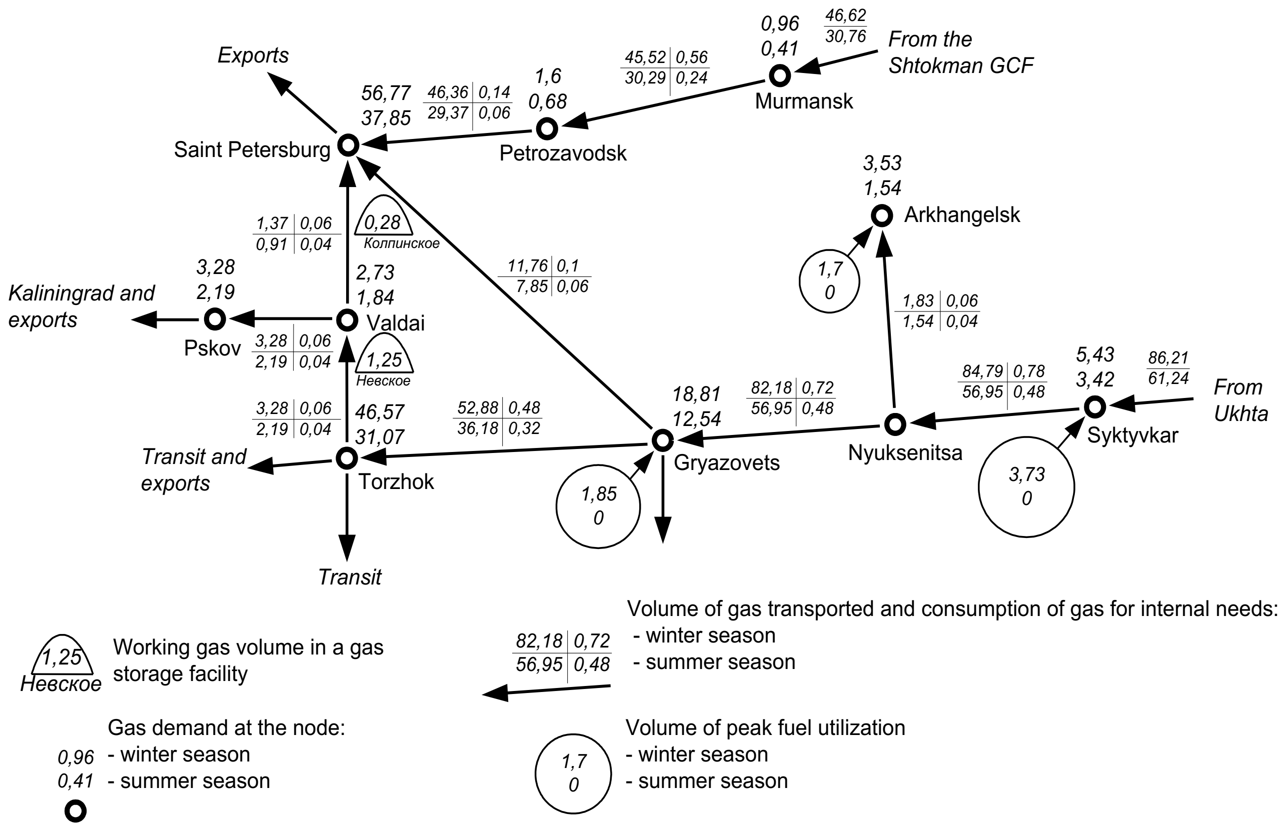

Figure 6. Regulation of seasonal irregularity of gas supply in the Northwestern Federal District in 2030 million tons of fuel equivalent.

The algorithm for the problem of evaluating the reliability of the gas supply system operation includes 3 modules used to solve the problem:

1. Probabilistic module.
2. Module for calculation of the system operation mode.
3. Reliability parameters calculation module.

The various nature of subproblems predetermines the use of various methods, namely: the method of statistical modeling for the composition of the calculated states of the system (Monte Carlo method); the method of calculating the distribution functions of random states of gas imbalances and the theorem of adding and multiplying the probabilities of various events; the method of flow distribution in networks for calculating operating modes.

In the probability module for simulating the states of the system facilities, a pseudo-random number generator (PRNG) is used to get the numbers evenly distributed within the interval from 0 to 1.

In the second module, the problem of calculating the optimal mode is stated as follows:

$$\sum_{i\in R_1} C_i^o - x_i^o + \sum_{i\in R_1} C_{0i} - x_{0i} + \sum_{i\in R_3} C_i^+ - x_i^+ \left(\sum_{i\in R_3} C_i^- - x_i^- \right) +$$

$$\sum_{(i,j)\in U} C_{ij} - x_{ij} + \sum_{i\in R_2} y_{0i} - x_i^d \rightarrow min$$

subject to

$$\left.\begin{array}{l} \sum_j \lambda_{ji} - x_{ji} - \sum_j x_{ij} + \lambda_i^0 - x_i^0 = 0 \\ 0 \le x_i^0 \le X_i^0 \end{array}\right\} i \in R_1;$$

$$\left.\begin{array}{l} \sum_j \lambda_{ji} - x_{ji} - \sum_j x_{ij} + x_{0i} - x_i^s = 0 \\ \text{where } x_i^s = x_i^I + X_i^{II} + X_i^{III} - x_i^d \\ 0 \le x_i^{I(\mathrm{II,III})} \le X_i^{I(II,III)} \\ 0 \le x_{0i} \le B_i \\ 0 \le x_i^d \le x_i^I + X_i^{II} + X_i^{III} \end{array}\right\} i \in R_2;$$

$$\left.\begin{array}{l} \sum_j \lambda_{ji} - x_{ji} - \sum_j x_{ij} - \lambda_i^+ - x_i^+ = 0 \\ 0 \le x_i^+ \le \min\{X_i^+, S_i\} \\ 0 \le x_i^- \le \min\{X_i^-, V_i - S_i\} \end{array}\right\} i \in R_3;$$

$$\sum_j \lambda_{ji} \cdot x_{ji} - \sum_j x_{ij} = 0 \qquad i \in R_4$$

$$0 \le x_{ij} \le X_{ij} \qquad (i,j) \in U.$$

The minimum discounted costs of gas delivery to consumers and the mathematical expectation of damage due to undersupply of gas for individual nodes are considered as a criterion. The constraints in the form of equations represent gas balances of the corresponding nodes, while the other constraints are set as bilateral inequalities.

In the third module, the above reliability indicators are determined for each design consumer node, and integral performance values, i.e. its utilization factor, are determined for each facility (MGP, UGS, field).

The model of synthesis of reliability of a complex gas supply system. To find the optimal reliability of the GSS, we propose a two-stage methodological approach that solves the following problems [22]:

Stage 1. Determination of equivalent reliability characteristics (dependences of mathematical expectations of actual capacity and discounted costs on the set capacity) for gas main pipelines, fields, and underground gas storage facilities, as well as for facilities storing reserves of gas and other fuels at the consumers' end that allow using them as gas substitutes. For this purpose, we employ the models of reliability analysis of GSS facilities.

Step 2. Optimization of redundancy means of the gas supply system. In doing so we assume that the problems of the upper hierarchical level should be solved first: the network flow problem, i.e. the justified volume of gas production in gas production centers as well as the volume and directions of inter-district gas flows are determined. This solution should be detailed in the seasonal gas consumption optimization model and it must be the basic input for the two-stage approach to model optimal reliability.

We formulate the problem of determining the optimal combination of redundancy methods satisfying at each node of the calculation scheme the balance of incoming and outgoing mathematical expectations of capacity of facilities, providing the consumers with the required volume of gas and reserves of the alternative fuel with the given reliability and under the given constraints:

$$\sum_{(i,j)\in U} \left(c_{ij} x_{ij} + k_{ij} y_{ij} \right) + p_j z_j \rightarrow min$$

$$\sum_{i\in \Gamma_j^+} \left(\lambda_{ij} x_{ij} + \pi_{ij} y_{ij} \right) + \alpha_j z_j - \sum_{j\in \Gamma_j^-} x_{ji} = \begin{cases} -Q, \ j = s; \\ 0, \ j \ne s,t; \\ B, \ j = t. \end{cases}$$

$$x_{ij} \le d_{ij}; \quad 0 \le y_{ij} \le d_{ij}^r - d_{ij}; 0 \le z_j \le Z_j \quad .$$

The minimum of the objective cost function is considered as a criterion. It shows balances of incoming and outgoing capacity of facilities with existing redundancy (x) and with additional redundancy means for these facilities (y), as well as taking into account the supplies of a backup fuel (z). For each node, a balance of incoming and outgoing capacity should be maintained (as per Kirchhoff's First Law). The last line shows two-way capacity constraints of facilities.

This problem is solved by standard methods of linear programming.

Figure 7 shows the results of the optimization of system reliability for the Northwestern Federal District during the winter season of 2030, which details the solution of the problem of seasonal irregularity. In order to meet the actual gas demand of the federal subjects in the Northwestern Federal District with the production-to-demand ratio of 0.99, it is required to build up redundant capacity to supplement the actual capacity of the elements, as well as redundant fuel reserves at a number of consumers in the district, as shown in Figure 7.

4. GSS integrated development models of the third hierarchical level

These include ***the models for the determination of optimal parameters of GSS facilities taking into account their reliability***. The overall process of deciding on the optimal parameters presupposes the following:

1. Multi-variant consideration of the ways of prospective development of the facility under consideration.
2. Analysis of its reliability.
3. The optimal choice of a reasonable option on the basis of calculation of technical and economic performance indicators and integral reliability indicators.

Thus, for example, *the problem of the determination of justified values of parameters of the MGP currently being designed, while taking into account its reliability,* in general terms is formulated as follows.

Based on the average daily MGP capacity (Q), its technical and process (T), reliability (N), and technical and economic performance indicators (E), the basic scheme of the MGP and redundant final backup methods (r) to determine the diameters of a line for line pipes, the number of CSs and installed GPUs that would maximize income Z from gas sales, provided that the specified reliability standard of P^* of gas supply is to be complied with.

$$Z = f(T, N, E, r) \to \max$$

$$P = y(Q, N, r) \geq P^*$$

The average daily calculated capacity (Q) is determined based on the annual calculated capacity of the MGP taking into account the coefficient of non-uniformity of gas consumption. For MGPs without underground gas storage (UGS) facilities at the consumers' end, it is typically assumed to be 0.85, while for branch lines of the trunkline it is 0.75.

Technical and process indicators (T) are as follows: the MGP length, the list of the number of lines and corresponding diameters, the list of standard sizes of rated GPU capacity (the number of considered options for LPs and CSs).

Reliability indicators (N) are understood as the rate of failure and recovery of LPs and GPUs. As a normative reliability indicator of gas pipeline P^*, we take reliability factor K_n. Its current value (P) is the ratio of the mathematical expectation of performance to its rated value:

$$K_n = \frac{M[Q]}{Q_n}.$$

Technical and economic performance indicators (E) are understood to be: specific annual operating costs and capital expenditures for MGP LP; specific annual operating costs and specific annual capital expenditures proportional to the installed CS capacity; specific metal inputs.

As a result of solving this problem of synthesis (optimization) of structural reliability of the MGP currently being designed the following parameters are determined: the number of lines; corresponding optimum diameters; the number of CSs; the number and length of LPs; the number of operating and redundant GPUs at each CS; optimum rated capacity of GCUs; metal inputs in LPs.

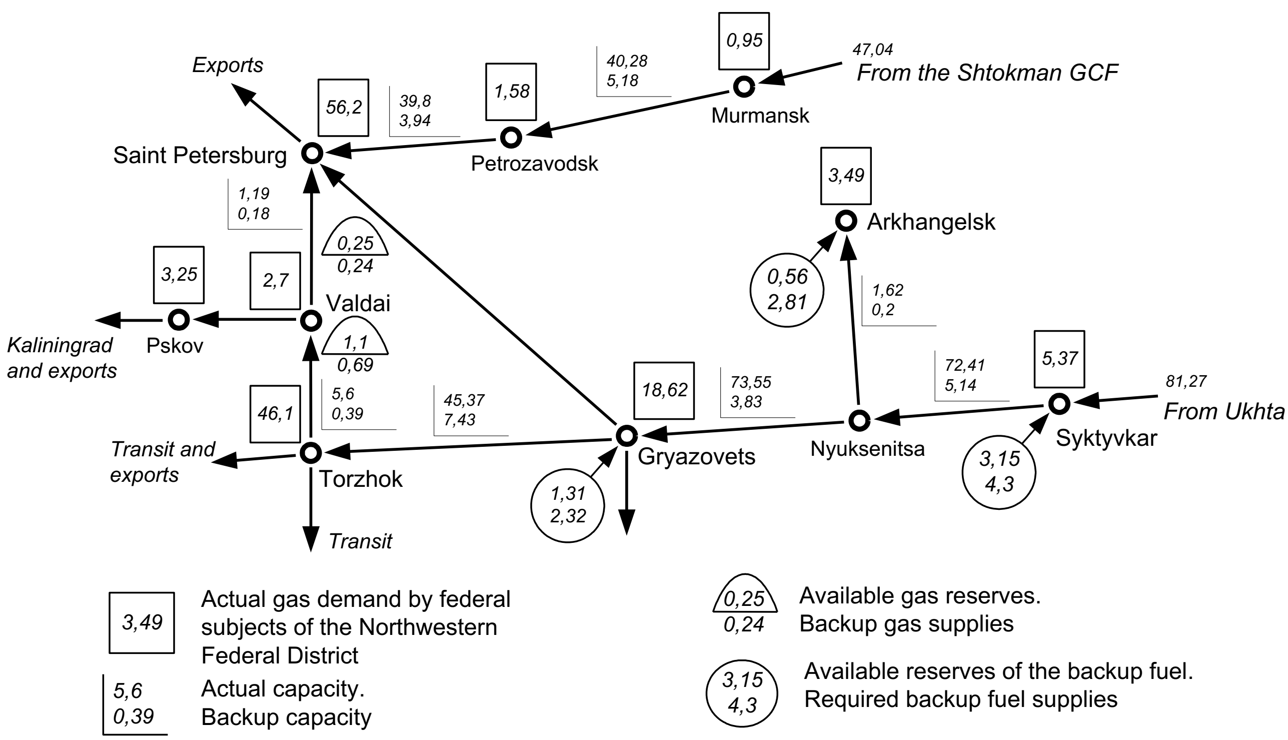

Figure 7. Optimal supply redundancy of the gas supply system of the Northwestern Federal District in the winter period of 2030.

The number of all possible considered options of the MGP currently being designed is equal to the product of the numbers of MGP LP options and GPU standard sizes for the CS and the maximum number of backup units at the CS, which should not exceed the number of operating units.

The above stated problem can be treated as a combinatorial optimization problem. The research-based engineering experience attests to the fact that the number of pipeline development options is relatively small, and all of them can be accounted for by simply cycling through the entire set.

Table 1 shows the results of parameters optimization taking into account reliability of the Kovykta GCF-Irkutsk-Beijing gas transportation system.

5. Comprehensive problems of pricing in the development of gas supply systems

We deal with the following three pricing problems:

1. Determination of retail prices and tariffs for natural gas for individual categories and groups of consumers and federal subjects of Russia.

2. Determination of the components of the wholesale gas price for federal subjects of Russia.

3. Determination of the supply and demand equilibrium between natural gas suppliers and consumers.

Determination of retail prices and tariffs for natural gas for individual categories and groups of consumers in federal subjects of Russia

Here, retail prices and tariffs for natural gas are modeled for selected categories and groups of consumers [4].

Modeling of the average tariff for gas for certain categories and groups of consumers of a federal subject is defined as an arithmetic sum of average tariffs of gas production and gas transportation companies of Gazprom PJSC, independent gas production companies, and gas marketing companies that distribute gas in the given region. That is, according to the existing scheme for gas producing and gas transportation companies, distribution systems of high, medium and low pressure gas pipelines, the path of gas supply to consumers in the region is considered. The analysis of natural gas balance (its incoming and outgoing parts) in the region for a specific period of time is provided. The cost estimates of financing for production, transportation, and gas distribution serves as a basis to determine the cost of production, contributions to investment funds, profits for auxiliaries and payments into the budget. That is, there are contingently variable and contingently fixed costs for which the average tariff (price) is calculated.

$$T_y^{\text{avg}} = T_{\text{gas-aux}}^{\text{avg}} + T_{\text{oil-gas}}^{\text{avg}} + T_{\text{gas-aux}}^{\text{avg}} + T_{\text{vat}} .$$

The two-rate tariff for gas for certain categories and groups of consumers of the federal subject is calculated as the sum of products of the rate for daily capacity and estimated gas demand and annual capacity, as well as the rate of the value added tax.

$$R_n = T_n^{day} \times q_n^{\max} + T_n^{year} \cdot Q_n + T_{vat} .$$

Methodological and practical issues of studying the impact of prices and tariffs for natural gas were used in determining the profitability levels of various aluminum production options at the Bogoslovsk Aluminum Smelter (BAS), see Figure 8 [23].

The profitability level of the Bogoslovsk Aluminum Smelter is set as a function of primary aluminum prices at London Metal Exchange, Table 2.

The data presented in the table shows that the efficiency of the plant's operation by years may decrease due to a significant increase in natural gas prices and tariffs. Even given a relatively high LME primary aluminum price of over $1,500 per ton in 2020, the production of the plant's marketable products may prove to be not profitable.

Table 1. Optimization of gas transportation system parameters Kovykta GCF – Irkutsk – Beijing, with reliability factored in.

Parameter	Kovykta GCF - Irkutsk	Irkutsk-Beijing
Diameter and number of lines	1220x2+1420	1420
Pipeline length, km	470	2170
Number of CSs	2 (3)*	16
Number of installed GPUs	9	6
Number of backup GPUs	3	3
GPU type	GPA-Ts-16	GPA-Ts-16
Resulting reliability	0.978	0.974
Capacity of a single CS	128.5	82.9
Specific capital expenditures	2.35	2.32
per 1 km, million USD		
Net present value, mln. USD	36,035	25,263
Internal rate of return, %	58.9	25.2
Year of loan repayment	7	7
Metal inputs, thous. tons	886	1634

Determination of wholesale gas price components for federal subjects of Russia

This problem is solved in two stages [24]. At the first stage (the direct problem) for the existing gas supply system for a given period of time on the basis of the network flow model, the optimal gas distribution and dual estimates (marginal nodal prices) are calculated.

The problem makes use of an address-based algorithm that allows determining the volume of gas entering consumption node *i* from any node *r*, it makes it possible to distribute the cost of gas transmission over the links between gas consumption nodes.

With the help of the address-based algorithm, the nodal gas price is spread over eight constituents $\overline{h}_i^M = \overline{h}_i^1 + \overline{h}_i^2 + \overline{h}_i^3 + \overline{h}_i^4 + \overline{h}_i^{M5} + \overline{h}_i^{M6} + \overline{h}_i^{M7} + \overline{h}_i^{M8}$, that are determined as based on the following: $\overline{h}_i^1$ – gas production; $\overline{h}_i^2$ - gas losses; during production $\overline{h}_i^3$ – by gas transportation; $\overline{h}_i^4$ – by losses due to transportation; $\overline{h}_i^{M5}$ – marginal gas production premium; $\overline{h}_i^{M6}$ – marginal gas production added loss; $\overline{h}_i^{M7}$ - marginal gas transportation addition; $\overline{h}_i^{M8}$ - marginal added gas transportation loss. The first four constituents represent the cost-based gas price at the node of the calculation scheme, the remaining constituents represent the marginal markups added to this price.

On the basis of the above methodological approach for the aggregate Unified Gas Supply System, direct and dual problems of linear programming were solved by calculation for year 2005. Cost-based and marginal nodal prices are determined using the address-based algorithm, see Figure 9. The prices for federal subjects of Russia set by the RF Federal Energy Commission (FEC) are also shown here.

Such a methodological approach to determining the components of the wholesale price of natural gas makes it possible to evaluate in an unbiased way the wholesale prices set by the RF FEC and shows the bottlenecks in the gas supply system where the price increase takes place.

Determining the balance of supply and demand between suppliers and consumers of natural gas.

Gas consumption and supplies are considered in terms of market competition in the single-product wholesale market [4]. The natural gas market in the Russian Federation is scattered across various federal subjects, therefore, wholesale prices of gas supply and consumption will also vary. The gas supplier is Gazprom PJSC, a monopolist company, therefore it is impossible to determine the equilibrium price of gas purchase and sale, as the monopolist maximizes their profit by simultaneously setting the values of gas price and sales volume. It would be advisable to suggest a regulator that would suit both the monopolist and consumers. Such a regulator can be based on the concept of the two-person zero-sum game.

Gas consumers and gas producers place their bids into wholesale markets of federal subjects of Russia. Consumers want to buy gas at the lowest possible price, while producers are willing to sell it as expensive as possible. There is a conflict of interest between the supplier and the consumer.

This conflict can be resolved by solving the problems of the flow of the cost of extreme capacity of gas production and transportation:

$$\sum_{(i,j)\in U} \delta_{ij} z_{ij} \to ext$$

(i.e. $\sum\limits_{(i,j)\in U} \delta_{ij} z_{ij} \to min$ or $\sum\limits_{(i,j)\in U} \delta_{ij} z_{ij} \to max$);

$$\xi_{ij} z_{ij} - \sum_{i\in \Gamma_j^-} z_{ji} = \begin{cases} -\left(\overline{Z}_u + \overline{Z_T^T}\right), & j = s; \\ 0, & j \neq s,t; \\ 3, & j = t. \end{cases}$$

$$0 \le z_{ij} \le \overline{z}_{ij}, (i,j) \in \overline{U}.$$

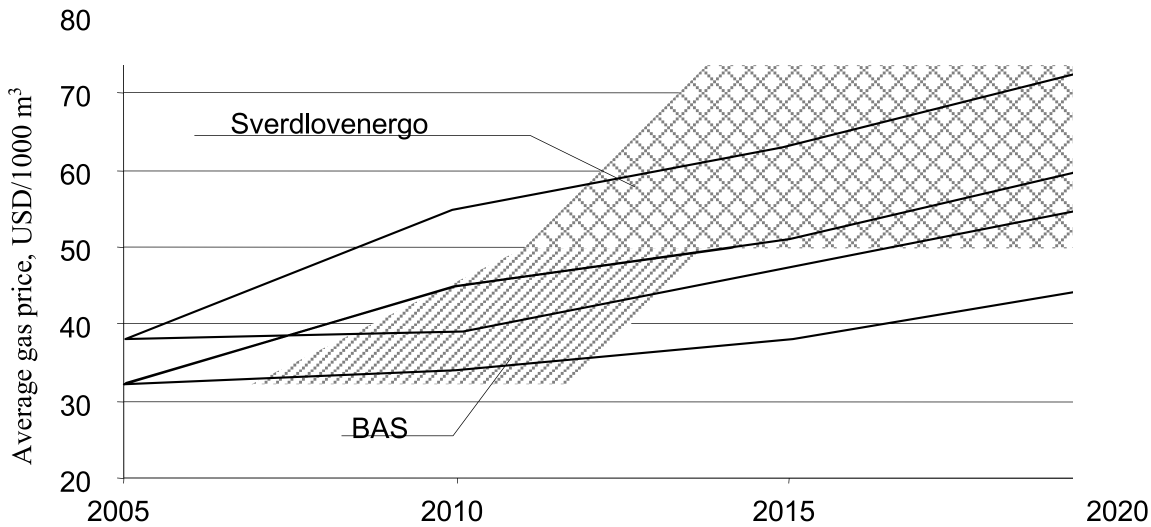

Fig. 8. Dynamics of natural gas prices for Sverdlovskenergo and BAS.

Table 2. Dynamics of profitability of the bogoslovsk aluminium smelter.

Indicators		Profitability, %			
		2005	2010	2015	2020
1. LME primary aluminium price, USD/t	1200	- 3.1	- 7.8	- 12.5	- 17.9
	1300	2.5	- 2.4	- 7.3	- 13.0
	1400	8.1	2.9	- 2.2	- 8.2
	1500	13.5	8.1	2.7	- 3.5
	1600	18.8	13.1	7.6	1.2
	1700	23.9	18.1	12.4	5.7
	1800	29.0	22.9	17.1	10.2
		100	123	139	165
2. Dynamics of increase in average prices of energy resources, %	Natural gas				

The objective function minimizes or maximizes the capacity of gas production and gas transportation flows. Balances of gas cost inflow and outflow at the nodes of the calculation network and constraints on cost flows and links of the calculation graph are shown.

If the problem is stated as that of searching for the minimum performance and transport, then we arrive at the problem of the most favorable distribution of cost flows from the point of view of gas suppliers (the most expensive production and transport companies will be selected first as part of the optimal plan, while the cheapest ones will be the last to make it to the plan). In this case, the declared cost is satisfied by the minimum volume of production and transportation at the maximum selling price.

If the problems is stated as that of searching for the maximum performance of gas production and transportation, then we arrive at the problem of the most favorable distribution of cost flows from the point of view of gas consumers (here, the cheapest production and transportation companies will be selected first as part of the optimal plan, while the most expensive ones will be the last to make it to the plan).

The declared value is satisfied by the maximum volume of production and transportation given the minimum sales prices.

A rational solution can be found in an iterative process that results in optimal cost flow allocation plans from the point of view of consumers and gas suppliers. The natural gas producing and transportation companies most efficient from the view of consumers and suppliers are selected. The capacity of these sources decreases by some Δ-value, i.e. new constraints are defined. The iterative calculation process continues until the minimum and maximum objective functions coincide with some specified error.

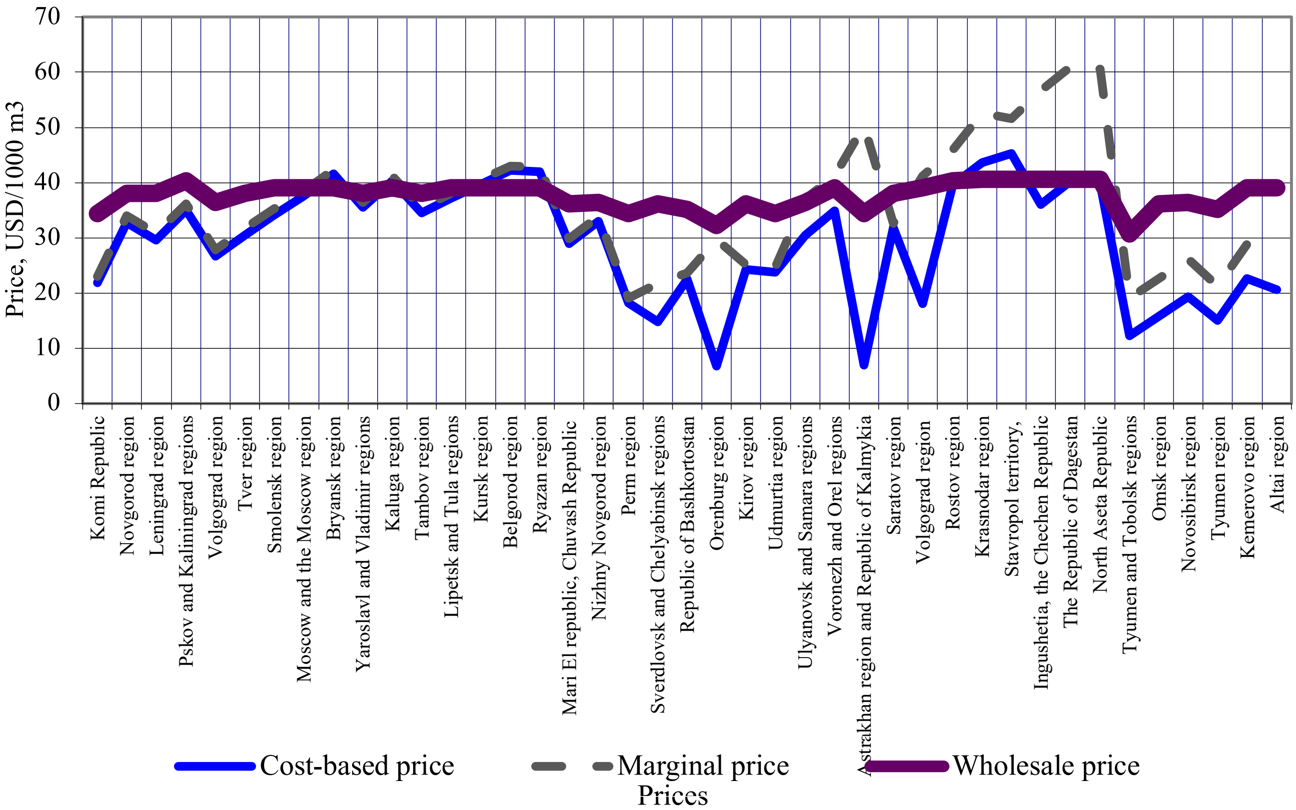

Figure 9. Wholesale gas prices calculated or set by the RF Federal Tariff Service for federal subjects of Russia.

Solving the problem may result in three options.

1. Gas purchase prices at wholesale markets are equal to sales prices of gas sources and routes of gas supplies to consumers.
2. The desired gas purchase prices will be higher than gas supply prices. In this case, more gas will be purchased at the same cost given a lower price.
3. The gas purchase prices will be lower than the gas supply prices. Given this relationship, consumers will buy less gas at the same cost.

In the first option, finding the balance of supply and demand is considered complete. The second and third ones require further research, which should determine at what prices of gas consumers and suppliers their objective functions will prove equal.

The testing and identification of the model's possibilities in studying the optimal cost flows from the point of view of gas suppliers and consumers was carried out on the basis of the calculation scheme of gas supply of the Ural Federal District.

Eight iterative calculations were performed. The eighth iteration resulted in the convergence of the values of the objective functions given the specified error. Gas consumption volume declared and received as a result of optimization in the scattered markets is shown in Table 3. In the gas markets of nodes 3 – 8, the declared prices of gas purchase are less than the prices offered by the gas supplier. Therefore, 20.2 billion m^3 less gas will be purchased at the Igrim node market for the same cost of gas purchase and sales; accordingly, a smaller volume of gas will be purchased in the markets of the following nodes: Nizhnyaya Tura – by 37.7 billion m^3, Polyanskaya – by 12.4 billion m^3, and Surgut – by 1.6 billion m^3. On the other hand, in the markets of nodes 6 and 7 the desired gas purchase prices are higher than the gas supply prices, therefore, at the Dolgoderevyanskaya node it is possible to buy 0.5 billion m^3 more gas than it was declared, and at the Tyumen node it is possible to buy 0.9 billion m^3 more gas.

V. Conclusion

1. Taking into account the general issues of aggregation of companies of gas supply systems, the hierarchical modeling of optimal development was considered, which is: 1) structure optimization and investment processes; 2) optimization of seasonal gas consumption, reliability analysis and synthesis; 3) optimization of parameters of a facility with its reliability factored in, as illustrated by the main gas pipeline.
2. The principles of gas pricing and methods of gas price calculation are given, namely the determination of the following: retail prices and tariffs, wholesale gas price, and its components for federal subjects of Russia, balance of supply and demand between gas suppliers and consumers.
3. Optimization calculations were carried out on the basis of the proposed multi-level modeling methodology for the gas supply system development: the volume of gas production and transportation for the averaged scenario of consumption in the Russian Federation, the choice of investment area, justified seasonal irregularity of gas consumption in the Northwestern Federal District, backing up the gas supply system of the Northwestern Federal District during winter periods, parameters of the Kovykta GCF-Beijing MGP.
4. On the basis of the developed methods of gas prices calculation, the following was determined: natural gas tariffs for Sverdlovskenergo, which made it possible to establish a justified level of the rate of return of the Bogoslovsk Aluminum Smelter depending on the London Metal Exchange primary aluminium prices;

Table 3. Gas consumption volumes as declared and resulted from optimization in scattered gas markets.

Node code	Node name	Inflow		Outflow		Entered the markets, billion m3.	Declared consumpti on, bcm	Gas shortage, bcm
		Link name	bcm	Link name	bcm			
3	Igrim	Nadym - Igrim	408.8	Igrim – Nizhnyaya Tura	348.5	60.3	80.5	20.2
4	Nizhnyaya Tura	Igrim – Nizhnyaya Tura	348.5	Nizhnyaya Tura - Polyanskaya	137	211.5	249.2	37.7
5	Polyanskaya	Nizhnyaya Tura – Polyanskaya	137			145	157.4	12.4
		Dolgoderevenskayaя – Polyanskaya	8					
		Total	145					
6	Dolgodereve nskaya	Tyumen – Dolgoderevenskaya	27.5	Dolgoderevenskaya - Polyanskaya	8	19.5	20	-0.5
7	Tyumen	Surgut – Tyumen	60.4	Tyumen – Dolgoderevenskaya	27.5	32.9	32	-0.9
8	Surgut	Urengoy – Surgut	11.3	Surgut – Tyumen	60.4	0.9	2.5	1.6
		Surgutgazprom	50					
		Total	61.3					
Total						470.1	541.6	71.5

components of the wholesale natural gas price for federal subjects of Russia that are instrumental in making unbiased evaluation of the price level set by the the RF Federal Energy Commission.

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