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Midterm Development Conditions for the Electric Power Industry of Russia under Hard Price Constraints

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Abstract—The paper considers the required economic conditions for the implementation of midterm plans for the development of the electric power industry in Russia based on financial and economic modeling with allowance for uncertainties in the growth rate of electricity demand and fuel prices, the scale and capital intensity of existing power plant renovation and the development of non-carbon energy sources. The area of industry development options is determined, which is being implemented in the context of the continued average electricity sales price regulation policy below inflation. The need for systematic measures in the pricing policy of the state for the successful development of the electric power industry in the medium term is shown.

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Introduction. Hitting the ceiling for the extensive growth of the Russian economy within the framework of the so-called raw material development model and the structural problems of the domestic economy manifested during the 2014–2015 financial and economic crisis determined the relevance of the analysis of possible strategies for its postcrisis development (see, for example, [1–3]). Almost all such studies emphasize the role of the fuel and energy complex as the most important infrastructure economic component, contributing to sustainable economic growth by increasing the competitiveness of nonenergy industries, the service sector, and the new digital industry.

Similar functions of the fuel and energy complex are also recorded in the Draft New Energy Strategy of Russia, which, in particular, requires the energy sector to "stimulate the development of the economy and improve the standard of living of the population by expanding the scope and quality of energy services while restraining energy prices and increasing investment demand for domestic products and tax revenues to budgets of all levels " [4]. Based on these priorities, the state pricing policy in the energy sector (especially in the electric power industry) has recently focused on the regulation of domestic prices within inflation.

However, macroeconomic requirements that set fairly tight price limits for the electric power industry should not contradict the objective economic conditions necessary for the implementation of production and investment decisions by sectoral economic agents, which in the existing, competitive environment are guided by the conditions for the return on investments. In the postcrisis economic conditions, these agents are faced with diverse uncertainties in the markets of electricity, fuel, equipment, affecting the production scale, level of net cost and the need for financing capital investments. In this regard, a quantitative assessment of the electricity price regulation necessary for the industry and desirable for the state (society) is extremely important. It allows economic agents to adapt their business strategies in a timely manner to the changing macroeconomic situation, and the state, to improve in a timely manner, the system of pricing and investment promotion in the electric power industry.

A methodological approach to assessing the economic conditions for the development of the electric power industry and pricing policy parameters. Until now, the issues of the state investment and pricing policy in the electric power industry have been considered without a pronounced mutual coordination. There is a representative range of work devoted to the selection of the economically optimal structure of generating capacities in terms of public investment efficiency. However, in these works, insufficient attention is paid to the elaboration of financial and economic tools for the implementation of socially effective investment decisions [5, 6]. In parallel, reasonable parameters of the state pricing policy in the electric power industry are discussed, which allow balancing the interests of consumers and energy companies. However, most of these works either focus on the short-term analysis horizon (less than 3–4 years) [7, 8], or they also affect long-term, investment aspects, but exclusively at the level of qualitative analysis [9, 10].

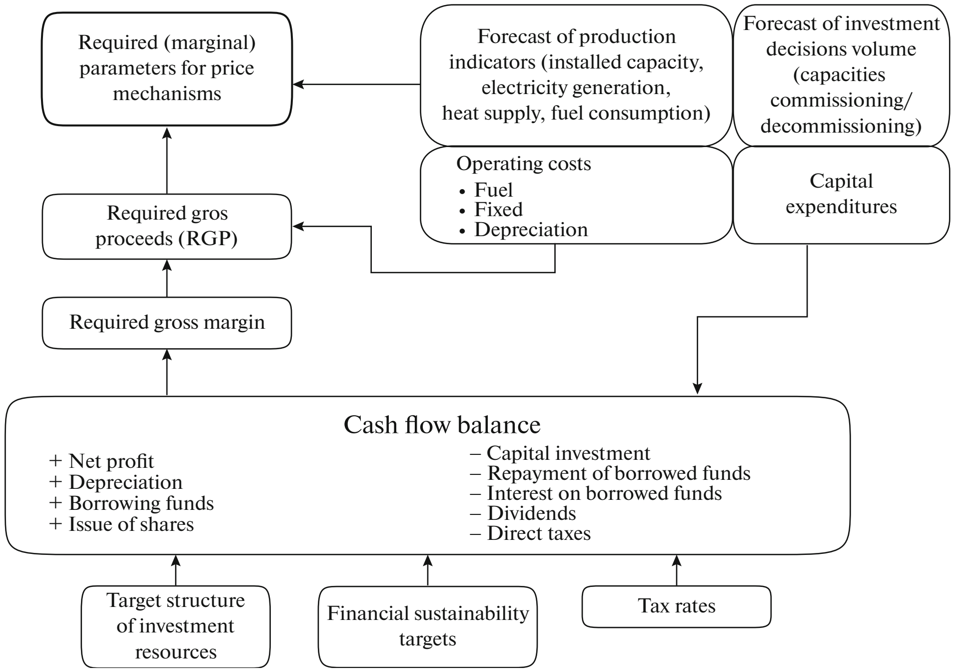

Fig. 1. Conceptual forecast scheme of the industrial energy gross revenue requirement.

In this regard, it becomes especially relevant to quantify the ramifications of various external factors (demand for electricity, technological priorities in investment activity, fuel prices) on the dynamics of the average selling price for electricity for end consumers.

The quantitative assessment of the required economic conditions for the development of the electric power industry is based on a set of financial and economic models of the industry and its key production segments developed by the ERI RAS: nuclear, hydro and thermal generation, electricity transmission and distribution [11]. It is used to forecast the price consequences of various production and investment programs of individual production segments and the industry as a whole based on the calculation of its gross revenue requirement.

In the economic sense, gross revenue requirement reflects the minimum amount of cash flow that ensures guaranteed financing of investment and operating expenses of the industry (or its individual segment), as well as tax and financial expenses, including servicing and repayment of borrowed funds. The schematic diagram for calculating the predicted gross revenue requirement dynamics for each production segment is shown in Fig. 1. The source data for the calculation of gross revenue requirement are production and investment program parameters, detailed by generation types. These parameters include the following:

(A) Installed capacity.

(B) Electricity output.

(C) Heat supply (for thermal generation segment).

(D) Fuel consumption by type (gas, fuel oil, coal).

(E) Volumes of commissioning/decommissioning of generating capacities and corresponding volumes of capital investments.

Another group of source parameters is formed by macroeconomic indicators evaluating not only the dynamics of expenses in the enlarged cost structure, but the volumes of financial and tax expenses as well, including:

(A) Inflation index.

(B) Interest rates on loans and borrowing.

(C) Dividend yield.

(B) Underlying tax rates.

Finally, another type of source data is historical financial and economic indicators of each production segment of the industry. Their values are formed on the basis of regularly updated annual and quarterly reports of generating and power grid companies in Russia. The most important of these historical indicators are revenue (by type of products), operating costs, depreciation, gross and net profit, investment, borrowed capital and interest payments for its servicing.

An important component of the economic calculations is to ensure the conditions of financial stability of each production segment, which is determined by the maximum allowable indicators of the capital structure and profitability and the level of debt burden. For this purpose, the gross revenue requirement model calculations use the target financial (rating) indicators, such as the debt/EBITDA ratio, as well as the share of borrowed funds in noncurrent liabilities.

In general, the gross revenue requirement is calculated from the formula (a more detailed description is given in [12]):

$$TRR_t = VC_t + OMC_t + D_t + FX_t + PT_t + \frac{NI_t}{1-r}, \quad (1)$$

where *TRR* (Total Revenue Required) is the gross revenue requirement; *VC* is the variable costs: fuel for thermal (TPP) and nuclear (NPP) power plants, water charges for hydroelectric power plants (HPPs); *OMC* (operational & maintenance cost) are the maintenance and operation costs (semifixed costs); *D* is the depreciation of fixed assets; *FX* is the financial expenses (mainly payment of interest on borrowed capital); *PT* is the property fund tax; *NI* is the required net income; *r* is the income tax rate; and *t* is the payroll year.

The operating cost dynamics (fuel and semifixed) is estimated based on the production indicators of each production segment, and the depreciation is estimated on the basis of changes in fixed assets value with allowance for the disposal of existing facilities and the commissioning of new ones.

The required net income indicator when calculating the gross revenue requirement for each production segment is determined on the basis of the cash flow balance equation as the difference between the total annual financing needs (capital investments, working capital replenishment, loan repayments, dividend payments) and all other external and internal sources (depreciation, borrowed funds, issue of shares, state budget funds). Thus, the net income is a "closing" source of financing, balancing insufficient funds, primarily external financing, the volume of which is limited by the indicators of financial stability indicated above.

Characteristic of the midterm uncertainty of economic indicators of the electric power industry in Russia. Being an integral part of the energy and economy of Russia, the electric power industry is subject to the influence of diverse uncertainty factors, which to one extent or another determine the dynamics of operating and investment costs and, as a result, the necessary volume of gross revenue requirement and electricity prices. This paper considers a cumulative effect of the main factors of uncertainty on changing economic conditions for the functioning and development of the industry in the postcrisis period.

As a source option (*option 0*), a production and investment program was adopted which generally corresponds to the conservative option of the Master Plan of Electric Supply Facilities (hereinafter referred to as the Master Plan), approved by the Government of the Russian Federation in 2016, but with two significant amendments. The initial option assumes, firstly, the continued gas price regulation "below inflation"; secondly, a more conservative technical policy for renewal of existing thermal power plants (TPPs), aimed at extending their lifetime by partial equipment substitution for similar, rather than technically advanced, equipment. It should be noted that this is exactly the scenario for the renewal of TPPs proposed by the Ministry of Energy of the Russian Federation as the main one in the competitive admissions of TPP modernization projects for thermal power plants.

Changes in the pricing policy on the domestic gas market have traditionally been an important factor affecting incentives to improve energy efficiency and intensify interfuel competition in the electric power industry. In the course of the conducted analysis, the impact of rising gas prices (by 20% by 2025 in real terms, excluding inflation) on the volume of the gross revenue requirement in the electric power industry was estimated (*option 1*).

Such a rise in gas prices will undoubtedly become an important but insufficient condition for the transition to the more advanced strategy for updating existing TPPs. This transition should be accompanied, firstly, by active government incentive measures for generating companies to implement projects using advanced equipment (this is especially true for gas-fired power plants). The second condition is no less active action to overcome the technological gap in a number of power engineering items through the localization or own development of generating equipment with cost reductions relative to imported analogs in mass production. To assess the influence of a more capital-intensive, but technologically advanced, TPP renewal strategy on the economic conditions for the industry development, option 2 was considered, which involves replacing the retiring gas-fired TPPs with combined-cycle and gas turbine units in a volume corresponding to the Master Plan parameters (up to 40–50% of the total capacity subject to the renewal).

Uncertainties associated with the postcrisis recovery and subsequent steady economic growth rate are reflected in the dynamics of domestic electricity consumption. In the medium term, this uncertainty is not so great and is estimated (taking into account the difference between the scenarios of the Master Plan and the Energy Strategy) by 2025 at 8–10%. However, the additional demand for electricity and capacity will require an increase in investment costs for new construction or an expanded renewal of existing TPPs. *Option 3* makes it possible to assess the influence of the demand factor on the gross revenue requirement growth of the electric power industry, provided that all additional increase in capacity and electricity output is carried out by thermal power plants. In contrast, *option 4* provides an assessment of government policy regarding the increase in the share of low-carbon energy: HPPs, NPPs and RES-based power plants with an increase in their capacity by an additional 10% compared to option 1.

The variation of each of the factors will affect the amount of operating and investment costs in individual production segments of the electric power industry. The qualitative characteristics of these changes are

Table 1. Qualitative effect of uncertainty factors on the gross revenue requirement components of the electric power industry

Industrial segment	Option 1	Option 2	Option 3	Option 4
Thermal Power Industry				
operating costs	Growth	Decrease	Growth	Decrease
investment costs	–	Growth	Growth	Decrease
Low-carbon Power Industry				
operating costs	–	–	–	Growth
investment costs	–	–	–	Growth
Electric power transmission and distribution				
operating costs	–	–	Growth	Growth
investment costs	–	–	Growth	Growth

The changes are given relative to the previous option, for option 1 relative to option 0.

presented in Table 1, and their quantitative analysis based on the results of financial and economic modeling is presented in the article below.

Analysis of the influence of individual factors on the electricity price dynamics and financial indicators of the industry in the transition from the baseline to the target scenario. One of the key factors affecting the future dynamics of the final price for electricity is the capital intensity of the considered options for the industry development. Figure 2 shows the change in the total volume of industry investments in the transition from option 0 to option 4.

At the same time, the volume of capital investments in options 0 and 1 completely coincide, since these options differ only in the rate of fuel price rise. In other options, only one of the factors varies, which allows us to assess numerically the contribution of each factor to the cumulative change in the investment needs of the electric power industry.

Thus, an increase in the TPP renewal rate, accompanied by the transfer of a significant number of operating steam power units to the combined cycle with a significant increase in fuel efficiency, will lead to an increase in total industry investments for 2016–2025

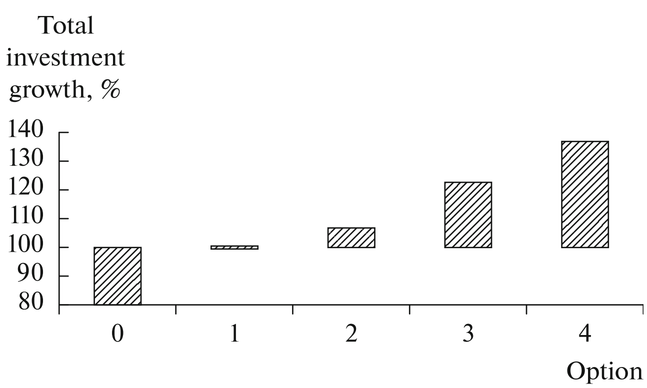

Fig. 2. Factor-based variation of the electric power industry investment needs (100%—option 0).

by 7.5%. A subsequent transition to options 3 and 4, which are based on a higher (target) demand scenario, will lead to an even greater growth in the investment demand of the electric power industry due to the need to build new generating capacity. The growing demand for energy and capacity in option 3 is provided by additional TPP commissioning; at the same time, the necessary investment will increase by 23% relative to option 0. If the increase in the required capacity is mainly provided by low-carbon energy (RES-base power plants, NPPs), then the total investment will increase even more, by 37%, and the investments as of 2025 by 72% (option 4).

The investment structure demand in various scenarios of the postcrisis development of the industry is characterized by significant changes (Table 2). So, in option 2, a deeper conversion rate of existing TPPs using modern gas turbine technologies is involves the additional growth of thermal energy investments by about 20%, which leads to a noticeable increase in their share in industry investments.

In option 3, the growth of thermal energy investments is further enhanced due to higher demand for electricity, covered by the commissioning of new TPP capacities. As a result, the share of the power industry in industry investments reaches 43%, compared with 36% in the "zero" version. The share of low-carbon generation (NPPs, HPPs, RES-based plants), on the contrary, scales down.

The most radical structural shifts occur in option 4. The intensive development of low-carbon energy (primarily RES-based power plants and, to a lesser extent, NPPs) leads to an increase in its share to 37% compared to 31% in the zero option and 25% in option 3 (at the same level of demand). The share of the heat power industry on the contrary decreases to the initial 36%, while the contribution of the power grid complex remains approximately the same for the options, varying from 29 to 34%.

Through the investment indicators and fuel costs, the above uncertainty factors also affect the dynamics of the industry-specific gross revenue requirement (Fig. 3). Calculations show that a factor of accelerated growth in gas prices[1] by 2025 in option 1 will lead to an increase in the total gross revenue requirement of the industry by 3% compared to option 0. The influence of high gas prices together with a change in the TPP renewal investment decision structure additionally causes a little less than 1% increase in the gross revenue requirement (option 2). The transition to a higher level of demand for electricity and capacity, accompanied by a corresponding increase in the investment demand of the industry, additionally increases the industry's gross revenue requirement by 5% (option 3), and the intensive development of low-carbon energy by another 5% (option 4).

Structural changes in the sectoral gross revenue requirement are not so pronounced as in the case of capital investments (Table 3). Thus, in option 1, an accelerated increase in fuel prices will lead to an increase in the gross revenue requirement of the thermal energy sector by about 5%, with the permanent revenue of other segments of the electric power industry, which will barely affect the structure of the industrial gross revenue requirement. In option 2, the increase in TPP fuel costs is supported by an increase in capital intensity of their renewal. However, this option assumes a higher efficiency of fossil fuel utilization in thermal generation (as a result of the renewal effect). As a result, the required revenue of thermal energy will additionally increase by only 1.5% and will not lead to significant structural changes in the industry-specific gross revenue requirement.

In option 3, which is characterized by a high level of energy consumption, the required revenue of the thermal power sector grows much more rapidly, by 12% relative to the zero option. However, a similar growth of the gross revenue requirement (about 7%) will be required for the power grid complex, mainly to expand the capabilities of the electric power grid infrastructure. The revenue of the low-carbon energy sector in this option will remain at the zero-option level.

The most significant structural changes are characteristic for option 4, which involves a much more intensive development of NPPs and RES-based plants. Their gross revenue requirement for 2025 will increase by 15 and 90%, respectively, and the total contribution to the industry-based gross revenue requirement will reach 24% compared to 19% in the zero option. The gross revenue requirement of thermal generation, on the contrary, will decrease symmetrically in comparison with option 3 (with the same level of electricity consumption). The revenue of the power grid complex will be slightly higher than in option 3, due to additional investments to adapt the power grid to the large-scale development of RES-based power plants.

[1] By 2025, an additional increase in gas prices will be 20% in real terms (excluding inflation).

Table 2. Structure of investment demand of the electric power industry according to the options for postcrisis development, %

Electric Power Sector	Option				
	0	1	2	3	4
TPP	36	36	39	44	36
NPP	19	19	18	16	17
HPP and RES	12	12	11	9	20
Power grids	34	34	32	31	29
Total industry	100	100	100	100	100

Table 3. Sectoral structure of the post-crisis power energy gross revenue requirement, %

Power sector	Option				
	0	1	2	3	4
TPPs	44	45	45	46	41
NPPs	13	13	13	12	13
HPPs and RES	7	6	6	6	11
Power grids	32	32	31	32	30
Sales	5	5	5	4	4
Total industry	100	100	100	100	100

An analysis of changes in the industrial gross revenue requirement by type of cost with varying factors of uncertainty under consideration—fuel prices, unit investment, demand (Table 4)—is of interest. This gross revenue requirement structure of the industry turned out to be very resistant to changes in the factors under consideration; however, certain patterns are still visible. Thus, the share of fuel costs reaches its maximum in option 1 (with a low depth of TPP renewal and a rapid increase in gas prices), and the minimum in

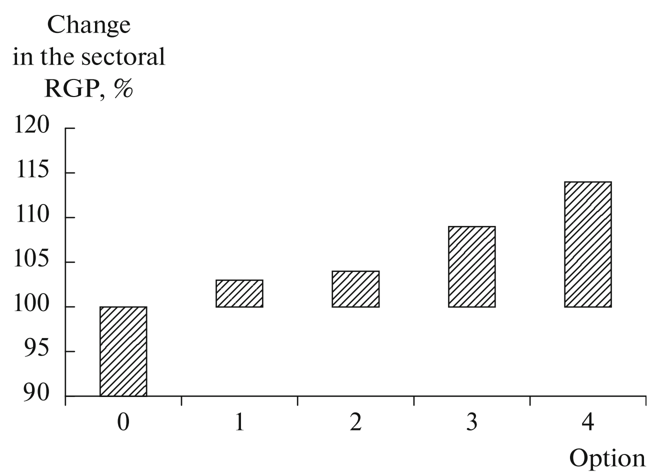

Fig. 3. Factor-based variation of the electric power industry gross revenue requirement as of 2025 (100%—option 0).

Table 4. Postcrisis gross revenue requirement structure of the electric power industry by type of cost, %

Gross revenue structure	Option				
	0	1	2	3	4
Fuel costs	30	32	30	30	28
Semi-fixed costs	38	37	36	37	35
Investment costs (including loan service)	26	26	27	27	30
Taxes	6	6	6	6	7
Total industry	100	100	100	100	100

Table 5. Alternative average annual growth rates of the ultimate price for electricity (excluding the inflation factor) for the period 2016–2025, including the generation and power grid components, %

Indicator	Option				
	0	1	2	3	4
Average annual growth rate					
ultimate price	–0.4	–0.1	0.0	0.5	1.0
generation cost	0.2	0.5	0.7	1.1	1.9
power grid tariff	–1.3	–1.3	–1.3	–0.6	–0.6

option 4, where the share of RES in the country's electrical balance sharply increases. Semifixed costs of the industry also behave the same way. On the contrary, the investment gross revenue component increases simultaneously with the growth of forecast demand and the capital intensity of investment decisions, thereby reaching the maximum in option 4.

The influence of the uncertainty factors under consideration through the investment indicators, fuel

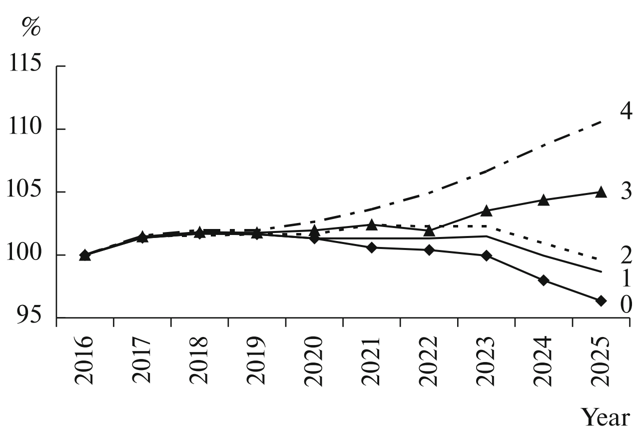

Fig. 4. Average electricity selling (ultimate) price dynamics (excluding inflation factor) for various power industry development options, % to 2016.

costs and gross revenue requirement is transformed finally into changes in price dynamics in the electricity, capacity and heat markets. The dynamics of the average retail price for electricity is considered below (in real terms, excluding the inflation factor) for the various postcrisis energy development options (Fig. 4), as well as the growth rates of the generation cost and network services (Table 5).

In the zero development option, the average selling price of electricity will decrease by 2025 by 4% in real terms due to low fuel prices and small investment demand.

With a more intensive increase in fuel prices (option 1), the effect of supplied electricity cost reduction will be much smaller, only 1.5% by 2025 compared to 2016. An increase in the share of modern equipment in the TPP renewal with a corresponding increase in the investment tariff component (option 2) will additionally impede the price reduction, which will stabilize at about the level of 2016 (excluding the inflation factor).

It is important to note that all the options under consideration at the basic level of electricity consumption ensure the dynamics of average electricity sales prices not higher than the average inflation for the period. This effect is achieved due to the possibility of restraining the power grid tariff growth significantly lower than inflation and, at the same time, the moderate growth of the generation cost (Table 5).

Options 3 and 4, suggesting a faster increase in electricity consumption, will require an increase in the average selling price for electricity at a rate higher than inflation. In particular, the provision of growing demand due to the construction of new thermal generation will lead to an increase in the real average selling price by 5% compared to 2016. The option covering the growing demand mainly due to the development of low-carbon energy will require an even greater rise in electricity prices, by 11% compared to 2016. This is due to the need not only to build low-carbon energy sources, but also to maintain the excess capacity of new TPPs to compensate for unstable renewable energy generation.

It should be noted that the rise in average selling prices for electricity even in these options will be quite restrained, since the accelerated price rise in the generation sector will be partially offset by a decrease (in real terms) in electricity transmission tariffs. The possibility of rising power grid tariffs below inflation is justified by the relatively low value of the required investments and the gross revenue requirement of the electric grid complex relative to the generation sector.

Conclusions. The analysis shows that even on a relatively small time horizon (until 2025), the uncertainty of the main external development factors of the electric power industry is quite large, which is reflected in the wide scatter of price and financial indicators in the industry. On the horizon after 2025, the scale of this "zone of uncertainty" will only increase with subsequent macroeconomic ramifications. Thus, the state, as a regulator of the electric power market, should clearly define in the coming years the technological priorities of investment policy in the electric power industry and the means for its implementation consistent with the pricing policy in the industry.

The above calculations show the fundamental achievability of the investment tasks of the industry with basic demand in the conditions of rigid electricity price regulation at the level below inflation. In particular, this possibility still exists with a fairly liberal state domestic gas price policy (with their growth by 1% above inflation). However, such inflation framing requires a number of systemic decisions by the state in the field of pricing policy, including the following:

(A) Tariff regulation of power grids according to the predicted gross revenue requirement noticeably below inflation (the calculations show the fundamental possibility of this pricing policy for the implementation of the minimum investment tasks of the power grid complex).

(B) Reducing the risks of excess revenues of HPPs and NPPs in the spot market (with increasing gas prices) and in the capacity market (with increasing prices for the TPP renewal program).

(C) Increase in TPP proceeds from the sale of thermal energy in the transition to the alternative-boiler model.

In addition, compliance with the condition preventing electricity prices rising above inflation means that a large-scale transfer of thermal power plants to a combined generation cycle becomes impossible without a significant reduction in the cost of medium and high power gas turbines, the mass production of which has not yet been established in Russia. This actualizes the development of specific financial mechanisms to support the relevant sector of domestic power engineering.

The analysis shows that the transition of the electric power industry to a more energy-efficient, innovative, diversified and environmentally friendly development trend in the next decade will inevitably lead to an increase in the cost of power supply to consumers above inflation (from 0.5 to 1% per year). In this regard, it is especially important to assess the impact of growing price dynamics on the economic growth rate and to identify the maximum acceptable price load on domestic electricity consumers. In order to reduce the burden on consumers in this case, it is possible to further analyze the feasibility of supporting energy companies by providing them with tax benefits and/or cheaper debt financing.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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