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Economic Analysis of Industrial Development: a Case of Russian Coal Industry

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ABSTRACT

This paper focuses on the economic framework of industrial development with a special focus on the assessment of prospects for coal power production industry development in Russia over the short-term and medium-term horizons. We analyse both social and environmental aspects of coal power industry from the standpoint of energy safety and sustainable development of the national economy. We distinguish the lines of improvement of technologies of coal power production as well as provide their economic assessment. Our economic assessment of the coal industry in Russia demonstrated that prospects for coal power industry development would be determined, in many respects, by coal price, conventional pollutant emission limits, stimulating policy of the government, and availability of high-performance technologies of coal-fired energy products generation.

1. INTRODUCTION

The long-term development of fuel and energy industry should completely satisfy the internal demand for fuel and energy resources in any given country and provide their export to external markets. There are some countries abundant in coal but experiencing institutional difficulties related to the development and modernization of that industry nevertheless. One of the typical examples is the Russian coal industry which has become the main focus of our paper.

One would agree that there are some problems of the use of the immense natural potentials in Russia. These problems relate to extremely uneven allocation of primary energy resources

within the territory of regions, reduction of exploration works over recent years, increased depreciation and ageing of the capital equipment in fuel and energy industry.

Estimated natural gas output will significantly vary depending on different ways of social and economic development of Russia. At the moment, major natural gas fields in the Western Siberia, providing the main actual output, are largely exhausted. The necessity of development of new complicated natural gas fields in the Eastern Siberia and the Far East; the need to establish the appropriate infrastructure under worsened geographic, geological, natural and climatic conditions of the natural gas production; and also the increased length of gas transmission routes will negatively impact the economy of the natural gas production and transportation (Lisin et al., 2015; Smil, 2015).

At the same time, the raw material source capacity in the coal mining industry is sufficiently more favourable. Russia has significant balanced coal reserves, which is over 200 bln tonnes (12% of world reserves) with 105 bln tonnes of those being explored at the moment. However, coal reserves are allocated extremely unevenly: over 80% of all of those are in Siberia, whereas the share of the European part of Russia is 10% only (Russian Federal State Statistics Service, 2016).

According to the Russian Energy Strategy for the period up to 2030 (Ministry of Energy of the Russian Federation, 2010; Kuznetsova et al., 2015), the consumption of power-generating coal in the power industry will grow, which will increase its production. Thus, the coal production in 2015 was 360 mln tonnes, including the coal stock of 115 mln tonnes for thermal power plants. The coal production in 2020 should rise up to 415 mln. tonnes, including 138 mln. tonnes as fuel for thermal power plants.

Meanwhile, there is a number of problems that hinder the development of coal power production industry. Increased ash content of coal from many deposits with poorly developed enrichment technologies decrease their competitiveness when compared to natural gas production and give rise to some problems when used as fuel. Also, significant number of coal deposits are characterised with unfavourable mining and exploration conditions. At some particular deposits, significant impairment of coal-mining capacities is expected, which requires commissioning of new facilities considering their technical re-equipment and intensification of production. It is worth to mention the fact that the enhancement of coal production would stimulate the increase in the volume of the interregional solid fuel traffic related to additional coal supply for thermal power plants (Lisin et al., 2015; Gorbacheva et al., 2015; Bugge et al., 2006).

According to the necessity to arrange the reliable provision of organic fuel for the power production industry requiring the maximum inclusion of coal into fuel balance of power plants, and, on the other hand, due to challenges related with coal production and increased use of coal as fuel for power plants, the problem of assessment of short-term prospects for coal power production industry development arise. The problem is discussed in this paper.

2. SOCIAL AND ENVIRONMENTAL ASPECTS OF COAL POWER PRODUCTION INDUSTRY DEVELOPMENT

Thermal power plants as enterprises performing their industrial and economic activities for heat and electric power production influence the social sphere through creation of new employments and via pricing for energy products.

The number of new job opportunities directly depends on technological level of energy products manufacturing and is determined by the installed capacity and number of generating units of the power plant (see Table 1).

Table 1. Headcount standards for thermal power plants

Installed capacity of the unit, MW	*Staff required for 1st power unit maintenance*	*Additional staff required for 2nd unit maintenance*
150 - 210	125	5
300	140	10
500 - 800	170	40

Source: Own development based on (TsOTenergo, 2016)

As some advanced technology is implemented, the single unit output grows. However, on a scale of the countrywide energy system, due to specific features of the energy products, the implemented output is fully determined by customers, i.e., additional employment is created due to increased demand for electric power, not switching to another generating technology. It is also worth to note that the implementation of any advanced power production technology doesn't lead to qualitative changes in automatic control system of the power plant; therefore, the staff structure and headcount corresponded to installed capacity don't undergo any change.

On the other hand, the implementation of advanced technology results to the improvement of electric power production efficiency as well as to the decrease of fuel consumption rate. However, at the same time, the cost of coal-fired power production facility grows, and depreciation and maintenance costs, which are included in electric power production cost, also increase. Depending on the ratio of efficiency growth due to fuel consumption decrease and the cost of power plant construction, the unit cost of electric power production when switching to more advanced technology may either decrease or increase.

Apart from technical and economic parameters, which define the level of technology, external factors, particularly fuel price, sufficiently affect the alteration of the unit cost of electric power production. At the low price of coal, the use of high-performance but expensive energy equipment may become economically unsound.

The cost of energy products, which has to lay within the range of socially affordable prices, is also limited by the development of coal-fired technologies. The energy product prices for the population of Russia are regulated by the government by using tariff restrictions. Tariff restrictions are figured up by the Russian Federal Tariff Service (FTS), which assigns the price limits (upper and lower) in accordance with the social policy of the government.

Considering that the cost of the natural gas is growing more rapidly than tariffs for energy products (Lisin et al., 2015; Russian Federal State Statistics Service, 2016), a threatening situation for power plants arises since fuel cost is the principal cost item for thermal power plants. In this case, switching to the prior use of coal as fuel in the future will allow to avoid the decline in profits of power generating companies. This means the reduction of investment programmes for technical re-equipment in the industry, which is one of important criteria of provision of the energy safety to the country. Also, the implementation of effective coal-fired technologies will allow to rein in energy product tariffs growth and to fulfil obligations of the government with regard to social programmes.

Another important aspect of development of coal power production industry is the impact of energy products on environment. Production activities of thermal power plants related to pollutant emissions such as sulphur oxides SO_X and nitrogen oxides NO_X. Non-exceeding of threshold limits of allowable pollutant concentrations in emissions is the criteria of environmental cleanness of a power generation facility.

In the absence of the emissions quota system no economic incentive for implementation of additional environmental measures as well as for switching to more advanced coal-fired technologies is provided. Table 2 demonstrates the values of CO_2/SO_2 emission rates for various carbon-fired power production technologies.

Table 2. CO_2/SO_2 emission rates for various thermal power production technologies

Technology	*Fuel consumption rate, TOE/kWh*	*Emission rate of combustion products, m^3/kWh*	
		CO_2	SO_2
Coal-fired generating units at supercritical steam conditions (SC)	215.25	0.304	0.00076
Coal-fired generating units at ultra-supercritical steam conditions (USC)	190.05	0.268	0.00067
Coal-fired generating units at advanced ultra-supercritical steam conditions (A-USC)	172.2	0.243	0.00061

Source: Own development based on (Sargent & Lundy, 2009; Franco et al, 2009; Breeze, 2014)

Targeting the construction of thermal power plants with elevated steam conditions as the way of development of power production industry will provide saving non-renewable resources (power-generating coal) and will decrease pollutant emission rate, which is extremely important within the context of permanently growing demand for electric power.

3. PROSPECTS OF RENEWAL AND DEVELOPMENT OF COAL POWER PLANTS

Coal-fired power production sufficiently contributes into the diversification of production structure of Russian electric power industry. However, within the last 10 years its share diminished from 29% to 24% over the country and from 19% to 16% in the European part of Russia (Russian Federal State Statistics Service, 2016; Ministry of Energy of the Russian Federation, 2016).

The share of the natural gas in fuel balance of power plants continuously increased within the last decade, whereas the share of coal diminished from 29% to 24%. The increase in the share of the natural gas in fuel consumption of thermal power plants in the European part of Russia was even more significant (from 78% to 87%) while the share of coal there dropped down from 12% to 9% (Russian Federal State Statistics Service, 2016).

Active power plants are characterised by wide spread of semi-fixed costs and fuel costs, which requires calculations based on variant models for substantiation of various standard solutions for renewal and optimisation of the structure of power generating facilities. Due to the ratio of the natural gas and oil prices (despite the intensive rate of increase of the natural gas price, the average cost of 1 TOE of the natural gas was less than the same of the coal), the improvement of coal-combusting technologies and solving of economic problems if coal is used at thermal power plants have fallen out of interest.

Nevertheless, Russia is one of the leading countries in the world in coal usage at conventional steam units of power plants, which is cost-effective today and will be profitable in the foreseeable future. Nowadays, there are 116 coal-fired thermal power plants in operation. Their basic facilities are units with 150–800 MW output capacity.

There is a severe need in improvement of technical performance of coal-fired units. The prerequisites are achievements in development of new materials and aspiration to reduce the negative impact on environment, including the CO_2 emission.

The efficiency of coal-combusting power unit may be increased from 37% to 42% by enhancement of turbine and boiler units, optimisation of thermal circuit, and reduction of auxiliary power consumption. Further raising of unit efficiency up to 43–46% (depending on the quality of fuel) is achievable by the increase in steam parameters (Dykas et al., 2011; Zhang et al., 2013).

Enhancement of reliability and cost-efficiency of actively operated equipment, modification of capital and auxiliary units, implementation of new technologies also contribute to the increase in the performance of coal-fired thermal power plants (Sargent & Lundy, 2009).

Usage of them depends on the equipment conditions, competitiveness of coal-fired generating facilities on the energy market, availability of funds, and other parameters of both internal and external environments.

In order to improve reliable and cost-effective operation of active equipment, well-known and proven technical solutions are applied. These include organising of examination and monitoring of technical conditions of coal-fired units with maximum age-dating. Commissioning of up-to-date automated control systems at coal-fired units is another way of enhancement of efficiency of coal power plants. It sufficiently improves their reliability, possibilities of operational control, economic and operational parameters.

Technological methods of nitrogen oxides NO_X suppression, particularly three-stage combustion, are the most mastered ways for improvement of environmental characteristics of coal-fired units. Also, the concentration of NO_X in the flue gases may be reduced by 30–65% by using the selective non-catalytic reduction technology which is widely applied in the EU, USA and Japan (Daood et al., 2014).

Table 3 represents the data on pollutant emissions by thermal power plants in Russia and abroad.

Table 3. Comparative data on environmental performance of high-capacity coal-fired thermal power plants in Russia and abroad

Emissions via flue gases		*Active thermal power plants in Russia*	*The EU standard on emissions*	*Japan (the best achieved result)*
NOx	mg/m³	300-570	200	80-100
SO_2	mg/m³	700	200	70-100
Ashy particles	mg/m³	50	30	10-20

Source: Own development based on (Wilde, 2009; Daood et al., 2014; Romanov et al., 2012)

Considering further toughening of standards on solid particles emission and implementation of norms on fine particles emission (PM2.5 and PM10), the application of innovative ash collection technologies becomes economically viable. However, due to liberal environmental legislation, desulphurisation systems are almost completely absent at Russian coal-fired thermal power plants. Today, diminishing of SO_2 emissions by coal power plants and development of effective desulphurisation facilities for them is still very actual in Russia.

A question of the need for reducing the concentration of post-combustion CO_2 and its capture from the power production cycle arises. Russia holds the fifth place in the world by its

emissions. It generates about 8% of overall world emissions; power production and transportation industries contribute about 84% of those (International Energy Statistics, 2016).

Significant reducing of CO_2 released into atmosphere by coal-fired thermal power plants is achievable by joint production of electric power and heat. Thermal power plants that implement such combined production of energy products and provide customers with district heating are known as heat and power plants (CHPs). These plants are widely spread in Russia and, according to adopted assessment, they reduce fuel consumption over the country by 1.4 mln TOE per annum. Gain in economic performance of coal-fired units of heat and power plants may reduce fuel consumption and CO_2 emissions by 20% and more (Lisin et al., 2016).

Sufficient increase in efficiency of operating thermal power plants may be achieved due to in-depth overhaul of their equipment. Some constructive solutions are required, taking into account specificities of combustion of particular Russian sorts of coal; thermal circuits of power generating units should be optimised; usage of expensive steels and alloys during development and manufacturing of new cost-effective power units has to be minimised.

At the present time, Russia, in spite of its extensive experience, noticeably lags behind in manufacturing and commissioning of up-to-date coal-fired power units. According to updated General Layout Plan for Electric Power Facilities for the period up to 2030 (Energy Forecasting Agency, 2010), the commissioning of up to 15 modern coal-fired power units was scheduled. However, in the coming years there is no orders for them from power generating companies. At the same time, for example, in China there are over 100 modern coal-fired power units already operated, with up to 1,000 MW capacity, up to 46% efficiency, and emissions of NO_x=90 mg/m^3, SO_2=120 mg/m^3, ashy particles=11 mg/m^3 (Mao et al., 2012; Yue, 2012)

The need in technical modernisation of coal-fired CHPs became extremely crucial. These plants are economically unsound for their operation without heat load and thus they are operated during the heating season only, which is about 4,000–5,000 hours per year (Lisin et al., 2016). Heat and power plants work according to heat load schedule and have no flexibility necessary for power adjustment in energy systems. Equipment and systems of heat and power plants were designed and manufactured about 50 years ago, they are worn, insufficiently automated and require the numerous staff for their operation and maintenance. Replacement of obsolete equipment of coal-fired heat and power plants with the new heating units with modern boiling and turbine equipment is a durable solution of the problem. Implementation of production technologies based on elevated steam parameters is necessary for improvement of economic efficiency of coal-fired power units.

4. INDICATOR TARGETS OF THE PROGRAMME OF MODERNISATION OF THERMAL POWER PLANTS

The Programme of Modernisation of Electric Power Industry in Russia for the period up to 2030 is a key document determining the development strategy for coal-fired thermal power plants in Russia.

According to this document with reference to thermal power plants, the following is expected:

- reduction of fuel consumption per output of electric power by thermal power plants from 0.233 to 0.210 kgoe/kWh in 2020 and to 0.189 kgoe/kWh in 2030;
- decommissioning (dismounting, conservation) of deteriorated and outdated equipment (5.7 GW up to 2020, 40.1 GW up to 2030);
- commissioning of new facilities at power plants (16.7 GW up to 2020; 57.5 GW up to 2030);

- efficiency of new natural gas-fired thermal power plants should be at least 50% by 2020 and at least 53% by 2030;
- efficiency of new coal-fired thermal power plants should be at least 38% by 2020 and at least 41% by 2030.

The Programme funds for the period up to 2030 are equal to 17.6 trillion roubles, including 10.2 trillion roubles for generating facilities, with 6.3 trillion roubles of those for thermal power plants.

Table 4 represents indicator targets of the Programme of Modernisation of Electric Power Industry in Russia reflecting significance of coal-fired technologies for the development of thermal power plants according to short-term and medium-term forecasts.

Table 4. Indicator targets of the Programme of Modernisation of Electric Power Industry in Russia

#	*Indicator target*	*2016-2020*	*2021-2030*
1	Decommissioning of deteriorated equipment of thermal power plants, GW	5.7	40.1
-	by fuel:		
	natural gas-fired thermal power plants, GW	3.99	38.62
	coal-fired thermal power plants, GW	1.7	1.42
-	by type:		
	condenser type electricity-only thermal power plants, GW	11,2	
	heat and power plants, GW	11,5	
2	Commissioning of new facilities of thermal power plants, GW	16.7	57.5
-	by fuel:		
	natural gas-fired thermal power plants, GW	10.71	51.11
	coal-fired thermal power plants, GW	5.86	6.36
-	by type:		
	condenser type electricity-only thermal power plants, GW	8.98	36.09
	heat and power plants, GW	7.76	21.47
3	Average efficiency of thermal power plants, %	46.4	49.4
-	by fuel:		
	natural gas-fired thermal power plants, %	50	53
	coal-fired thermal power plants, %	38	41
4	Average fuel consumption per output of electric power by thermal power plants, kgoe/kWh	0.210	0.189

Source: Own development based on (Ministry of Energy of the Russian Federation, 2011; Energy Forecasting Agency, 2010)

As it is demonstrated by the data hereinabove, despite the necessity of development of coal power industry from the standpoint of energy safety of the country, the Programme of Modernisation of Electric Power Industry in Russia gives preference to the development of the natural gas-fired thermal power plants production facilities. This circumstance is due to chosen economic mechanisms of implementation of the Programme.

5. ECONOMIC MECHANISMS OF IMPLEMENTATION OF THE PROGRAMME OF MODERNISATION OF THERMAL POWER PLANTS

Economic mechanisms of thermal power plants modernisation under the implementation of the Programme of Modernisation of Electric Power Industry in Russia and within the approach used for management in electric power industry presume the following:

- economically viable ratio of yields and risks of long-term investments into modernisation and construction of new power generating facilities;
- leading role of the government in the investment process for the purpose of secure provision of energetic safety of the country and its regions under the limitation of direct budget expenditures for investments into electric power industry;
- containment of additional investment burden on electric power tariffs for end customers;
- reduction of costs of energy equipment and construction of power generating facilities due to reorganisation of credit portfolio with acquisition of "long-term" loans and refinancing, including resources of Russian banks with state participation.

Financing of commissioning of main generating facilities of electric power plants is provided within terms of concluded contracts for power provision (CPP). Commissioning of auxiliary capacities is managed through modified mechanism of the long-term power market, which presumes the following:

- separated competitive capacity take-off (CCT) for operating facilities of power plants with limitations on technical and economic access conditions (it stimulates modernisation of generating assets);
- competitive selection of projects of new capacities for auxiliary CCT with further conclusion of CPP;
- pricing limitation on the cost of standard projects and yields for CCT concerning new capacities;
- guaranteed investments into commissioning of new capacities dictated by balanced requirements of energy system;
- inclusion of new projects on modernisation and construction of facilities of power plants in the programme of public-private partnership in electric power industry.

The following methods are applied for selection of new projects on modernisation and construction of power plants:

Assessment of comparative efficiency of standard solutions on technical modernisation and new construction of power plants (optimisation of technology varieties) on the basis of calculation of discounted expenditures and ranging according to efficiency of power generating technologies. Discounted unit costs per life cycle of applied technology of energy resources production are the criteria of assessment.

Systematic assessment of balanced and economically viable ways of development of electric power industry (optimisation of the scope of development of technologies) on the basis of dynamic optimisation of electric power industry development model. The minimum discounted cost of energy supply to the economy per planning cycle is the criteria of assessment.

Assessment of rational option of the generating capacities structure on the basis of balanced and circuit-operational calculations. The minimum deviations from the optimal capacity structure considering the cost of the single capacity of power generating units, operational factors and resource limitations are the criteria of assessment.

Adopted economic mechanisms of thermal power plants modernisation are primarily focused on commissioning of new capacities characterised by minimal operational costs. In this case, prospects of development of coal-fired generating technologies will be defined by coal price forecast, the ratio of coal and natural gas prices and pollutant emission quotas.

Obtained results of comparison of threshold power-generating coal prices that determine the economic viability of implementation of coal-fired generating technology, considering or not the pollutant emission quota system, are represented in Table 5.

Table 5. Coal price ranges determining the economic viability of implementation of coal-fired technologies from the standpoint of the minimum operational costs, considering or not the pollutant emission quota system

Technology level of coal-fired power generation	*Coal price range providing the minimum unit cost of electric power production, roubles/tonne*	
	excluding pollutant emission quota system	*including pollutant emission quota system*
Coal-fired generating units at supercritical steam conditions (SC)	0 - 662	0
Coal-fired generating units at ultra-supercritical steam conditions (USC)	662 - 7400	0 - 4280
Coal-fired generating units at advanced ultra-supercritical steam conditions (A-USC)	>7400	>4280

Source: Own development based on (Lisin et al., 2015)

The results represented in Table 5 allow to conclude that implementation of pollutant emission quota system results to market signals addressed to owners of power plants, indicating the necessity of implementation of more advanced technologies of coal-fired power production. Commissioning of higher-level technologies of coal-fired power production reduces pollutant emissions into atmosphere and also provides the lean usage of non-renewable natural resources. This matches the principles of the concept of sustainable development and creates the basis for the long-term sustainable development of the national economy.

At that point, consideration of emission quotas will lead to increase of prices on electric power generated by coal-fired thermal power plants. However, a single rise in prices on energy products for the purpose of development of the mechanism of power industry functioning which would comply with the principles of sustainable development should be considered acceptable. Assessment of possibility of implementation of systems stimulating care for the environment is one of objectives of Ministry of Energy, which in turn should determine the growth of electric power production cost and put it in line with the social policy of the government.

In order to match the principles of sustainable development, economic mechanisms of modernisation of thermal power plants should also include criteria of resource adequacy as well as environmental and social factors, not just those of commercial performance. With stimulating policy of the government and favourable economic conditions (e.g., coal price, power generating equipment price, heat electric power costs, terms of crediting, construction and maintenance, transportation abilities and costs), the coal power industry is able to dominate in the energy system of the country in the medium term. However, under existing conditions, the prominence of the natural gas over coal would continuously grow, and it will result to continuing trend of progressive exclusion of coal-fired power production from the market.

6. CONCLUSIONS AND DISCUSSIONS

At present, too little attention is paid to the institutional framework of the coal power industry in Russia. Its role and scope are not defined for the short-run or medium-run, while its economic preconditions have not been formulated properly by the policy-makers.

There are large coal deposits in Russia with favourable mining conditions. In turn, regions where those deposits are located need electric power and heat for their development. In order to satisfy such demand in energy products, the stimulating technical policy of the government is needed, as well as economic conditions for implementation of projects for thermal power plants construction and modernisation.

The programme of technical modernisation of operated coal-fired units should provide the gradual transition to higher-level coal-fired power production technologies. Implementation of such technologies results to significant reduction of fuel consumption as well as to improvement of environmental performance of the enterprise; however, it requires a bigger share of expensive steels and alloys for the construction of power generating units. This leads to significant increase of capital costs per installed capacity unit. From the economic standpoint, implementation of high-level technologies is viable nowadays for the construction of high capacity power plants.

According to the Russian Energy Strategy for the period up to 2030, the maximum inclusion of coal into fuel balance of power plants is provided. Given this, despite the severe necessity of diversification of fuel and energy resources consumption and decrease of dependence of power industry upon the natural gas, the transition to the prior use of coal-fired technologies does not occur. Moreover, exclusion of coal-fired power production by the natural gas-based one is carrying on. The existing trend in turn may result to incompliance with the energy safety requirements and, thus, to unsustainable development of the national economy. This circumstance has been caused by adopted mechanisms of the state policy on construction and modernisation of thermal power plants, since, first of all, these mechanisms take into account commercial performance of power generating facilities.

With stimulating policy of the government and competitive price on coal fuel, the coal power industry may achieve the dominant place in the energy system of the country in the medium term. However, under existing conditions, the prominence of the natural gas over coal would continuously grow, and it will result to continuing trend of progressive exclusion of coal-fired power production from the market.

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