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INDUSTRIES AND INTERINDUSTRY COMPLEXES

Technological Progress Opportunities in the Energy Sector of Russia

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Abstract—Based on the scenarios [1] for the transition of world energy in the period up to 2040 to a new technological base, a study was made of its implications for energy and the economy of Russia. The damage from the declining export of Russian fuel due to the acceleration of technological progress (TP) in the global energy sector, as well as possible direct and multiplicative effects of its achievements in the energy sector of Russia[1] are estimated. It is shown that with accelerated TP and the dynamics of domestic energy consumption obtained in the conservative scenario, it is possible to almost double the growth rate of the country's gross domestic product (GDP). The required financial and economic conditions and measures for restructuring the fuel and energy complex[2] are determined, so that the acceleration of TP in the energy sector could not only compensate for the expected decline in revenue from fuel exports, but almost double the growth rate of Russian GDP.

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Problem formulation. Technological progress in the 21st century is the main dominant factor in the development of energy in the world and in Russia. It shifted to the background the factor of labor resources in the fuel and energy complex (and to a large extent, their qualifications) and became the main component of its investment attractiveness, significantly lowering the importance of the fuel supply factor. Based on a scenario analysis performed by the Energy Research Institute of the Russian Academy of Sciences (ERI RAS) of the consequences of the world energy transition from fossil fuels to noncarbon energy resources [1], two extreme scenarios of the Russian energy development in the period up to 2040 are considered below, as well as the possible implications for the country's economy.

A conservative Russian energy development scenario continues the current trends in new technologies that have proved their effectiveness and corresponds to the homonymous version of the Forecast of the State Social and Economic Development up to 2024 [2] and its extension until 2036 [3]. Its main macroindicators[3] were used to calculate a balanced development scenario of the country's economy using a SCANER simulation data complex [4] for enlarged types of economic activities and manufacturing industries with breakdown by federal districts and extrapolation until 2040.

Russia exports more than half of the primary energy produced and, as our forecasts for the development of world energy markets have shown [1], in the conservative scenario it will continue to increase the export of all types of fuel, and world prices will not reach their peak levels in the period under consideration (2007–2008). New sanctions will follow the old ones, including limited access by Russian energy companies to borrowed capital, the latest technology and market channels. In this scenario, partial reforms will "correct" the low efficiency of the Russian economy and energy by increasing the share of investments in the economy, saving and government spending on the development of social energy and transport infrastructure, as well as reducing corruption, while retention of the existing financial, pricing and tax policies in the energy sector will keep stagnating the energy efficiency of the economy and technological progress in the energy sector of Russia.

An innovative scenario for the Russian energy sector development provides for accelerated TP at all stages of the technological cycle from energy generation to consumption, with optimistic expectations of an increase in the extended technological efficiency. But, unlike most developed countries, its implementa-

[1] The study of climatic and environmental factors, which, along with technological progress, influence the energy development rate and proportions, remains outside the scope of this article.

[2] The term fuel and energy complex (FEC) means a set of types of activities providing fuel extraction, specialized transportation, processing and centralized production of electric and thermal energy: the oil, gas and coal industries, centralized electricity and heat supply. The term "energy sector" includes the fuel and energy complex and the energy facilities of all fuel and energy consumers.

[3] Population, labor resources, labor productivity, gross domestic product, fixed capital investments, industrial production, population incomes, nonenergy exports and imports.

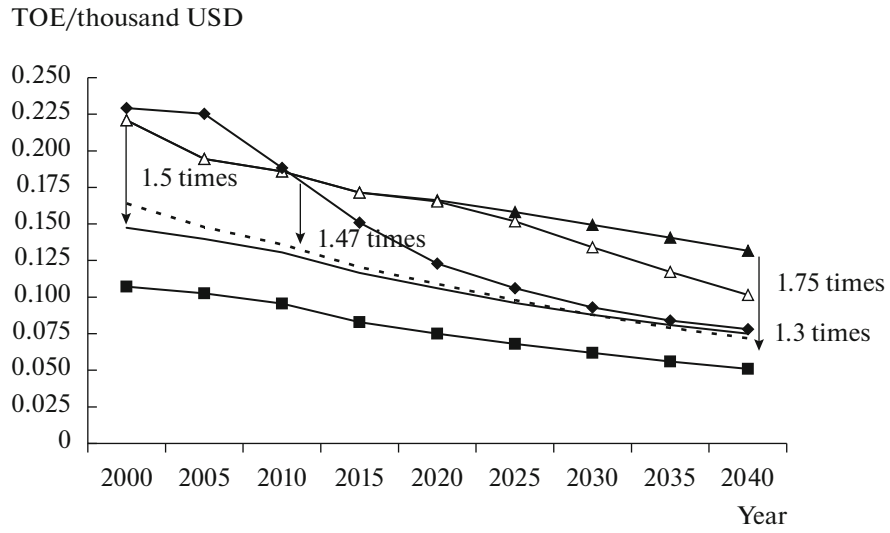

Fig. 1. GDP energy intensity of Russia in the conservative and innovative scenarios, TOE/thousand USD PPP 2016: –▲– Russia traditional; –△– Russia innovative; —— World; –■– OECD Europe; –◆– China; ----- USA. Sources: IEA, 2016 actual data, INEI RAS forecast data.

tion in Russia will require a radical business climate improvement in order to ensure the economic efficiency of new technologies.

An analysis of international and Russian forecasts showed a possibility to reduce from 1.75 to 1.3 times in 2015–2040 the excess of the Russian GDP energy intensity over world average values when transferring from the conservative to innovative scenario by intensifying the use of developed energy-efficient technologies in electric and heat energy[4] and other fuel consumers[5], as well as implementation of measures of organizational, intersectoral and product energy saving. The experience of large countries (in the United States the GDP energy intensity decreased by 30% over 15 years, in China, by half over 10 years, Fig. 1) indicates that a decrease in the GDP energy intensity in Russia in 2020–2040 from 20% in the conservative scenario to 40% in the innovative scenario is by no means ambitious. Iterative calculations on the SCANER complex made it possible to determine the marginal rates of growth and changes in the structure of the Russian economy that can be achieved in the innovation scenario with allowance for the volumes of primary energy domestic consumption obtained in the conservative scenario (with optimization of its structure).

At the same time, *in the innovative scenario for the development of world energy, the volume of international trade has significantly decreased and as well as prices for all types of fuel in comparison with the conservative scenario* [1]. The consequence of this in the Russian scenario will be a reduction in physical volumes, and especially revenue from Russian energy exports. Can (and how) TP in the energy sector of Russia compensate for these losses, is one of the acute research questions.

Economic development and domestic energy consumption. The Russian economy in the conservative scenario develops at an average annual GDP growth rate of ~1.6%. The accumulation standard will be about 20% of GDP, and the contribution of the fuel and energy sector to GDP will remain in the range of 21–20% and only by 2040 will decrease to 17%. In terms of GDP (in terms of purchasing power parity of currencies in international dollars), Russia will overtake Germany in 2035, staying the six-largest in the world, behind China, India, the United States, Indonesia and Japan.

The innovative scenario was developed for the dynamics of domestic demand for primary energy obtained in the conservative scenario, subject to the implementation of economically justified energy-saving measures in Russian conditions. It was shown that in the future this will ensure acceleration of the country's GDP growth rate by 1.7 times: under the innovative scenario relative to the conservative one[6]. Russia will be able to rise to fifth place in the world, ahead of Japan in 2035 and almost equal to Indonesia. At the same time, the accumulation standard will exceed 25%, and the share in GDP of energy-intensive resource-based industries will decrease from 12.8% in

[4] These are dozens of new technologies of the entire range of capacities for the storage and generation of electric energy based on organic and nuclear fuels, renewable energy sources, as well as improvement of energy management systems based on digitalization; for more details see [1, 5].

[5] These are hundreds of technologies, see [1, 6].

[6] The scenarios of economic development and the fuel and energy complex of Russia that are close in terms of growth rates are considered in [7].

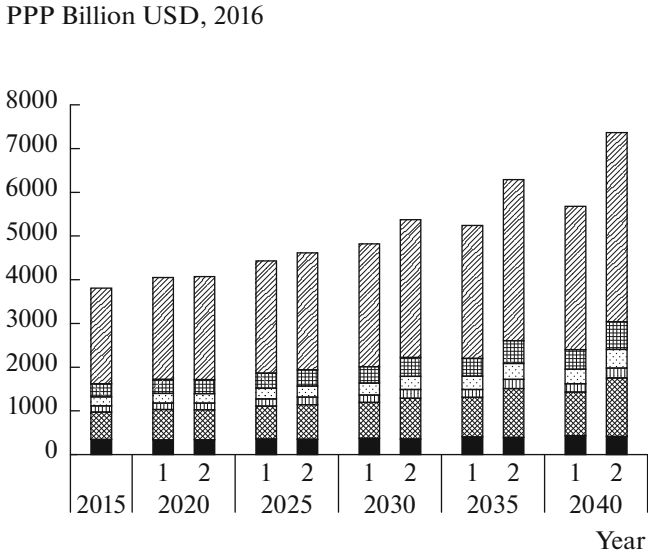

Fig. 2. Dynamics and structure of Russia's GDP in the conservative (1) and innovative (2) scenarios: ■ mining; ▨ industry; ▥ agriculture and forestry; ⬚ construction; ▦ transport and communications; ▨ taxes and services. Source: INEI RAS.

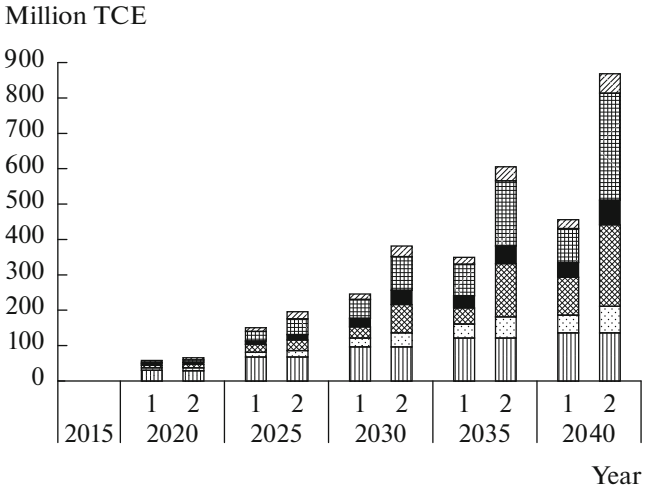

Fig. 3. Dynamics and factors of primary energy saving in the conservative (1) and innovative (2) scenarios: ▥ increase in primary energy consumption; ⬚ organizational energy saving; ▨ energy saving technologies; ■ sectoral economy structure; ▦ product economy structure; ▨ capacity utilization. Source: INEI RAS.

2015 to 9% in 2040 with an increase in the share of manufacturing industries from 24.4 to 27% and the service sector from 57 up to 59% (Fig. 2).

The Russian GDP energy intensity in 2000–2015 was one and a half times higher than the world average. This is due (along with the cold climate and large distances of the most expensive land freight transportation) to the resource-based nature of the economy and its significant technological inferiority. In the conservative scenario, this gap will increase from 1.47 times in 2015 to 1.75 times by 2040, while the Russian GDP energy intensity will decrease by 20%. In the innovative scenario, the excess of world average values will decrease by 1.3 times by 2040, and the GDP energy intensity will decrease to 0.1 TOE/$1000USD (see Fig. 1).

According to the innovative scenario, the volume of *energy saving*[7] in Russia will be 2.3 times larger than in the conservative scenario (Fig. 3) and will exceed 70% of the domestic primary energy consumption in Russia in 2040. More than half of the total saving in the period until 2030 and almost three-quarters of the next decade will be ensured by energy-saving technologies [6] and the improvement of the economy product structure with an increase in the product added value produced per unit of consumed energy. The implementation of these energy saving trends will require over the period from $500 to 740 billion US dollars of additional (compared with the conservative scenario) energy consumer investments and will create a powerful multiplier effect in the economy. In addition, in the innovative scenario, the increase in production capacity utilization will provide up to 7% of total energy savings, the improvement of the sectoral economy structure will add 10% and organizational measures 11% mainly through the use of information technology and robotic automation.

Primary energy consumption, according to the conservative scenario, will increase in Russia by 2040 by 15% compared to 2015, and its consumption by power plants and boiler houses will be 50–51% over the entire period. The share of the second largest energy consumer, the transport sector, will increase from 16% in 2015 to 17% by 2025 and will continue to stay at this level as a result of the electrification of railways and (from the middle of the period) automobile transport, as well as gas pipeline compressors. Additionally, the dominant motor fuels will be replaced by compressed and liquefied gas by 8% by 2040. Enhancing electrification will keep the share of fuel consumption for production and domestic needs at the level of 13%, and the share of its consumption as raw materials will increase from 7.6% in 2015 to 9% in 2040 (Fig. 4).

In the innovation scenario, with the same dynamics of primary energy consumption as in the conservative scenario, its structure will substantially change. Acceleration of the production, transport and household electrification, even with a double intensification of energy saving, will increase its consumption by 2040 by 38% (in the conservative scenario, by 21%). Noncarbon generation will provide 70% of the additional electricity generation: a quarter of the increase will come from nonconventional renewable energy

[7] Determined by subtracting the amount of primary energy consumption P per year t from the product of the predicted GDP_t value by the value of its energy intensity in the initial year of the period: $E_t = E_0 \times GDP_t - P_t$.

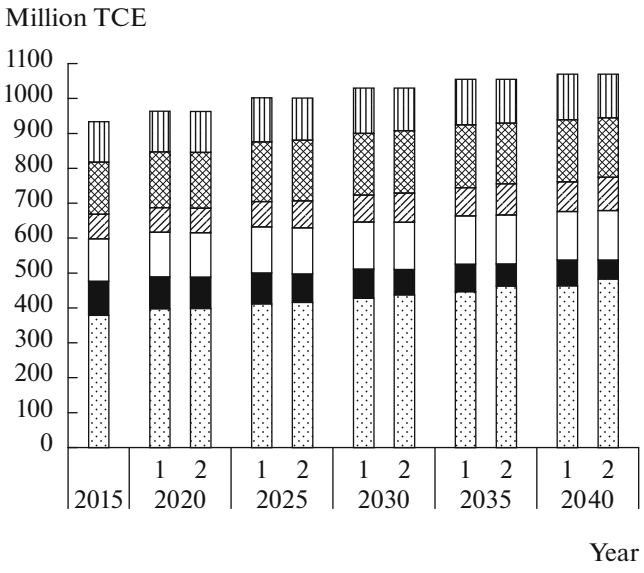

Fig. 4. Main primary energy consumption directions in the conservative (1) and innovative (2) scenarios: ⬚ power plants; ■ boiler houses; □ production needs; ▨ raw material needs; ▩ transport; ▥ communal needs. Source: INEI RAS.

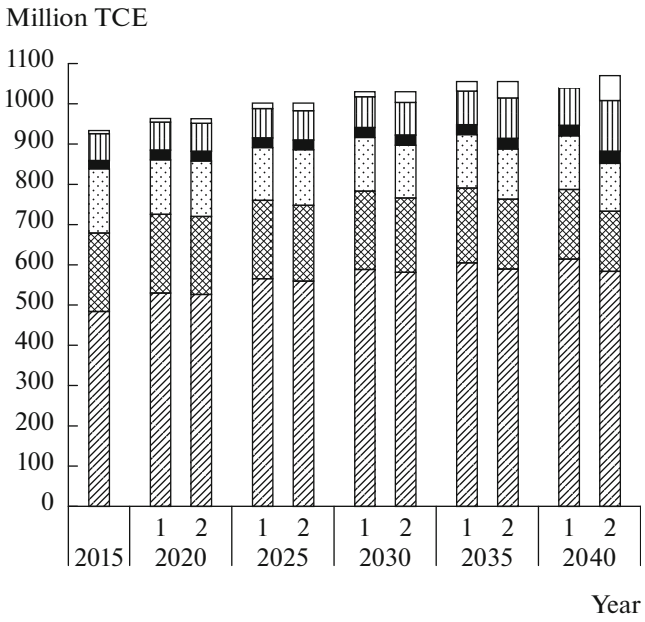

Fig. 5. Consumption of the main types of primary energy in the conservative (1) and innovative (2) scenarios: ▨ gas; ⬚ liquid fuel; ▩ solid fuel; ■ hydropower; ▥ atomic energy; □ RES. Source: INEI RAS.

sources, and more than half will come from NPPs. The output of thermal power plants will increase only by 1–2%, mainly due to the accelerated development of distributed electricity and heat cogeneration (Fig. 4, for more details see [6]).

Electricity generation by nonconventional renewable energy sources (NRES) amounted to 0.3% of its production in 2015 and will increase by 8 and 30 times under the scenarios, but their share in the electricity production in 2040 will be only 2.4% in the conservative and 6% in the innovative scenario. The development of NRES-based energy is constrained by the worst (compared to cheap gas) geophysical and economic characteristics and the location of their main resources in regions with low population and production density.

In the innovative scenario, TP acceleration will facilitate the development of NPPs and HPPs. Together with NRES they will increase the share of noncarbon electric energy in the primary energy domestic consumption by power plants from 34.5% in 2015 to 45% by 2040 (up to 38% in the conservative scenario).

In both scenarios, the prevailing share of natural gas will increase from 52% in 2015 to 57–55% of the total primary energy consumption in 2040, with a decrease in the liquid fuel share from 21% in 2015 to 17% in the conservative and 15% in an innovative scenario. The share of solid fuel will decrease from 17% in 2015 to 13 and 11% in 2040, respectively, with an increase from 10 to 13% and 19% of the share of noncarbon resource consumption (Fig. 5).

But these improvements in the innovative scenario of the country's energy consumption structure will require a change in the pricing principles for natural gas and an improvement in the tariff policy in electric and heat power industries.

Improving the energy efficiency of the economy and increasing the share of noncarbon energy resources in energy consumption to 19% by 2040 open up the opportunity for Russia to reach the global average economic growth rate according to the innovative scenario, while leaving greenhouse gas emission at the level of not more than 75% of 1990 in the period under review. But expensive borrowed capital, cheap fuel resources and much lower (relative to developed countries) incomes of the population objectively impede the use of advanced (but more expensive) technologies for the production and use of energy resources necessary for a deeper transformation of the energy consumption structure.

Conditions for the technological progress intensification in the energy sector of Russia. *Capital availability.* The main barrier to technological progress in Russia is the high cost of capital. Large exporters of products, including major fuel companies, before imposing the US and EU sanctions against Russia in 2014, had solved this problem by borrowing capital in foreign markets. This allowed them to massively upgrade production using the best world fuel extraction and processing technologies. The rest of the country's economy was recovering with much more expensive borrowed capital.

Table 1. Export prices for the Russian fuel on the world energy markets in the conservative (1) and innovative (2) scenarios, USD 2016

Indicator	2016	2020		2025		2030		2035		2040	
		1	2	1	2	1	2	1	2	1	2
Crude oil, bbl											
Europe	44	74	65	79	60	84	63	96	65	102	66
China	48	79	70	84	65	89	69	102	71	108	73
Pipeline gas, thous. cub. m											
Europe	180	262	242	285	274	277	268	301	282	312	284
China	176	173	183	176	186	180	185	192	187	201	191
Power station coal, t											
Europe	60	75	70	77	68	82	69	87	70	89	71
China	70	80	76	82	74	87	75	92	76	94	76

Source: [1]

The sanctions limited volumes and worsened the conditions for raising capital for export companies, and the subsequent stagnation of the economy raised the cost of capital in Russia. The indicator for this was the dynamics of the yield on federal loan bonds (OFZ), even with an inflation discount, it almost doubled in 2014 and only in 2017 returned to the presanction values, i.e., 6–7% per year. But even with the previous OFZ yield, the cost of borrowed capital could not be less than 9–10%, but actually 3–4% higher. In the world, new technologies for energy production and consumption are effective at a cost of capital of 3–5%, which constrains their application in Russia. New US sanctions will aggravate the situation by requiring the Central Bank of Russia to combine support for truly needed foreign exchange reserves with a policy of cheaper domestic borrowed capital. Without this, it is difficult to count on the intensification of technological progress in the country.

Domestic prices. The difficulty of reducing the cost of borrowed capital due to growing sovereign risks makes the price stimulation of technological progress in the energy sector especially relevant, since there are economic reasons for this.

Simulation of the evolution of world energy markets in [1] showed an increase from 2016 to 2040 of the equilibrium prices[8] for the export of Russian fuel in the conservative and innovative scenarios, respectively, by 2.3 and 1.5 times for oil, by 1, 5 and 1.2 times for coal, and for network natural gas, 1.7 and 1.6 times (Table 1).

Domestic prices for crude oil, petroleum products and coal exported by Russia are formed on the principle of equal economic feasibility with world market prices. Their level is controlled by the amount of customs duties and transport tariffs established by the state, and inconsistencies in oil product prices are compensated by the size of sales excise taxes for consumers. The system, which has been operating since the beginning of the 2000s, is now being upgraded: customs duties are being replaced by an increase in the severance tax. In this case, the increase in the cost of oil products for consumers is constrained by the introduction of negative excise taxes on gasoline and diesel fuel, and the prices of thermal coals depend on domestic prices for natural gas. Therefore, power plants and boiler houses are often supplied with cheaper screened out and refined coals as well as nontradable energy coals.

State price regulation for natural gas, which provides more than half of primary energy consumption and up to 60% of fossil fuels consumed in the country, remains nonmarket. Ten years ago, the policy of raising domestic gas prices aimed at equal export profitability was replaced by their increase initially to comply with the inflation rate, then by the "inflation minus" rule and finally by "freezing" after the double ruble devaluation in 2014 in order to support the population and energy-intensive industries. As a result, incentives for gas and energy consumers to increase energy efficiency and use noncarbon energy resources have disappeared. Coal producers are forced to budge on the position to gas in the domestic market, temporarily compensating for this by increasing exports due to the cheapening of coal production after the ruble devaluation.

The nonmarket nature of this pricing policy is demonstrated by the ratio of fuel prices in the domestic and foreign markets: in the European part of Russia (where three-quarters of the country's fuel is consumed), the consumer prices of the most efficient and clean gas fuel are only 10–15% higher than the price of

[8] Equilibrium prices correspond to the optimum production and consumption of the main types of fuel in the global energy markets. Actual market prices are usually higher than equilibrium ones due to political risks (only in 1998 and 2015 they fall below the equilibrium prices for one or two months). Therefore, equilibrium prices underestimate the volume of the Russian fuel exports.

Table 2. Wholesale prices for natural gas and coal in Russia, USD 2016/TOE

Federal District	Natural gas				Power plant coal			
	2016*	2025	2030	2040	2016*	2025	2030	2040
Price increase with the inflation rate (conservative scenario)								
Northwestern, Central Federal Districts	64	68	70	71	59	65	69	73
Southern, North Caucasian Federal Districts	65	70	71	73	68	66	73	74
Volga Federal District	59	64	64	66	54	62	66	70
Ural Federal District	53	58	58	60	48	50	54	58
Siberian Federal District	56	60	60	62	28	23	24	26
Far Eastern Federal District	48	51	51	53	44	49	50	51
Transition to net back parity prices (innovative scenario)								
Northwestern, Central Federal Districts	68	111	130	137	69	60	60	60
Southern, North Caucasian Federal Districts	72	120	147	154	73	60	62	61
Volga Federal District	64	100	118	122	56	56	57	57
Ural Federal District	59	87	102	106	49	44	45	45
Siberian Federal District	62	83	97	100	20	17	14	13
Far Eastern Federal District	57	102	129	136	45	53	53	54

* The scattering of the reported values is caused by the difference in fuel prices in the federal districts.

The gas prices were determined at the main gas pipelines nodes, coal prices at the railway stations and averaged for the respective territory of the country zone. Consumer prices (excluding preferential tariffs) will be higher than the given values by the value of distribution transport tariffs. Source: author's calculations.

power plant coal, whereas in the European market Russian gas is three to four times more expensive than Russian coal.

The condition for the implementation of the innovative scenario is the gradual increase starting from 2020 in the domestic natural gas prices to the level of equipotency with its prices on world markets, with their doubling (in dollars) by 2030 from the level of 2016 and subsequent synchronization with the world gas prices (Table 2). Such a measure is necessary to intensify energy saving, especially in the electric power industry and utilities, and will increase the contribution of the gas industry to the country's GDP.

The consumption of gas compared to coal gives consumers an additional economic (and environmental) effect of at least $4 USD/TCE. Therefore, coal is competitive in centralized gas supply areas if its price is less than the gas price by the indicated value. If the price difference is less than this consumer effect, coal can only be used by consumers not connected to gas supply systems.

Domestic gas prices in the innovative scenario will rise in 2025–2030 much faster than coal prices due to the transition to the principle of net back parity with export gas prices. In contrast, domestic coal prices in both scenarios are based on net back parity. But the world coal prices in the innovative scenario are lower than in the conservative one, which is reflected in the domestic prices (Table 2). It should be emphasized that even in the innovative scenario, the values of wholesale gas prices (and much more its retail prices) in Russia will be significantly (by a quarter in the western and southern regions and by half in Siberia) lower than in Europe: because of the high cost of exporting Russian gas. In contrast, the coal prices to the west of the Volga region will be close to world prices and noticeably lower only in the Urals and Siberia.

The tax policy provides for the waiver of the gas export duty when it is replaced by an increase in the severance tax (or another way of taking rent), similar to what is provided for by the oil and coal production taxes in Russia. This measure will intensify technological progress in the extraction and refining of oil and gas, as well as increase the flexibility of their reaction to changes in prices on world markets, increasing the competitiveness of Russian hydrocarbons.

Fuel export. The dynamics of Russian fuel exports are determined by the optimization of its volumes on world energy markets. In the conservative scenario, they will increase by 15% between 2015 and 2025–2030, and then slightly drop by 2040. In the innovative scenario, the dynamics of world fuel prices is much less favorable for Russia (see Table 1), therefore, the volume of Russian exports after growth by 12% by 2020 will decrease in 2035–2040 by 5–6% compared with 2015 (Fig. 6) [1].

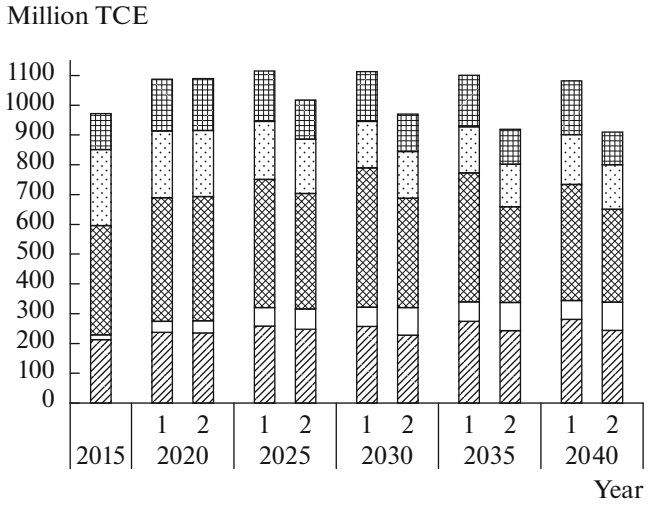

Fig. 6. Dynamics of Russia's energy exports and structure by fuel types in the conservative (1) and innovative (2) scenarios: ▨ pipeline gas; □ LNG; ▩ oil; ⬚ petroleum products; ▦ coal. Source: [1].

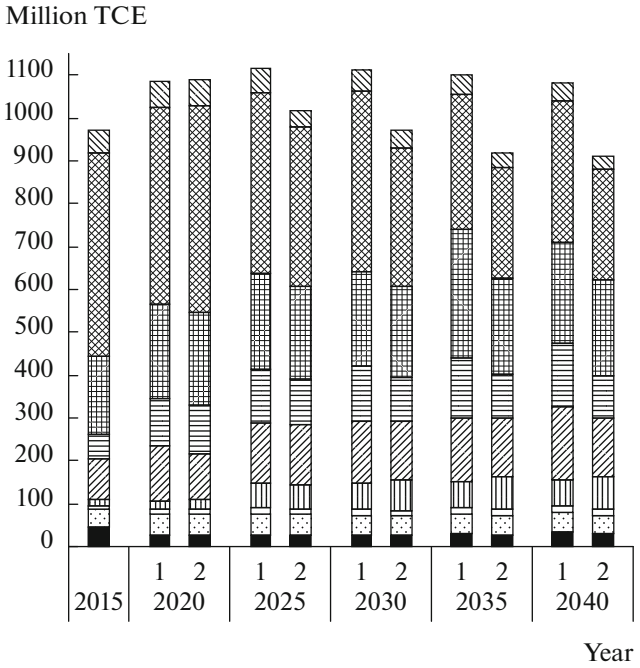

Fig. 7. Russian fuel exports to world markets in the conservative (1) and innovative (2) scenarios: ■ CIS gas; ⬚ CIS oil and oil products; □ CIS coal; ▥ A/P gas; ▨ A/P oil and oil products; ▤ AP coal; ▦ Europe gas; ▩ Europe oil and oil products; ▧ Europe coal.

The *export volume of pipeline and liquefied gas* will increase by 2025 by 32% in the conservative and by 30% in the innovation scenario, and by 2040 by another 10–9%. The share of gas in Russian exports will increase from 23.6% in 2015 to 32% in 2040 in the conservative and up to 37% in the innovative scenario. The development of technologies for the production and transportation of liquefied natural gas (LNG) in the Arctic will increase its supply by 4 and 7.5 times, respectively, and in the innovative scenario, it will more than compensate for the decrease in demand for Russian pipeline gas in Europe in other markets.

In the conservative scenario, *oil exports* will increase by 2% by 2025 compared to 2015 and then decrease by 10% by 2040 with an increase in sales of crude oil by 11% and a decrease in exports of petroleum products by 43%. The share of oil-based fuel in exports will decrease from 64% in 2015 to 51% in 2040 due to the decline in motor fuel consumption in Europe caused by the electrification of vehicles. In the innovative scenario, the volume of oil exports after a growth of 7% by 2020 will decrease by 28% by 2040 (see Fig. 6). But Russia can avoid a decline in oil sales either by reducing the tax burden on its production, or in the case of successful development of shale oil production that meets its geological conditions. This may be another version of the innovative scenario.

Coal export volumes will increase from 2015 in the conservative scenario by 41% until 2040, and in the innovative scenario by 22% by 2020 and then decline by 2040 below the level of 2015 (see Fig. 6). This will be caused by a deceleration in demand and a halving of the growth in world prices for coal (especially for power plants) against the background of increased costs for the extraction and transportation of Russian coal due to toughening requirements for environmental protection. Diversification of Russia's participation in global energy markets will continue. Fuel sales in the Asian market will increase by 2040 by 2.2 times in the conservative and 1.8 times in the innovative scenario, and its share in Russia's energy exports will increase from 17% in 2015 to 34 and 28%, respectively. Russian oil exports will dominate in Asia (46–44% in 2040), and the share of gas supply will increase from 9.6% in 2015 to 23% in the conservative and 35% in the innovative scenario (Fig. 7).

The European market will remain the main one for Russia in the coming period, but its share in Russian exports will decrease from 73% in 2015 to 57–59% in 2040. Oil exports to Europe will decrease by 8% in the conservative and by 18% in the innovative scenarios, and its share will increase from 49% in 2015 to 51% in 2040. Gas exports to Europe will increase under the scenarios by 20 and 13% with an increase in its share from 26 to 35% in the conservative and 42% in the innovative scenarios. Unlike the oil exports, coal supplies to the European market will decrease by 20 and 45% by 2040, and its share will decrease from 16% in 2015 to 14 and 11%, respectively [1].

Accelerating TP in the energy sector in an innovative scenario threatens Russia with a loss of 100 million TCE exports in 2025 and 170–180 million TCE/year in 2035–2040. They are almost evenly divided between the oil and coal export, and in monetary

Table 3. Revenue from fuel exports in the conservative (1) and innovative (2) scenarios, billion US dollars, 2016

Sector	2015	2020	2025	2030 *	2035 *	2040 *
Oil						
Scenario 1	243	173	170	169	177	150
Scenario 2		157	131	125	121	99
Gas						
Scenario 1	42	54	69	74	82	88
Scenario 2		55	73	87	95	100
Coal						
Scenario 1	17	16	17	18	19	21
Scenario 2		15	12	12	12	11
Total FEC						
Scenario 1	301	243	255	261	278	259
Scenario 2		227	217	224	227	209
% to 2015						
Scenario 1	100	81	85	87	92	86
Scenario 2		75	72	74	75	69

* Average for five years.
Sources: [8–10].

terms reach $50 billion USD per year at the end of the period. The volume of gas exports will decrease to a lesser extent, but its structure will substantially change by 2025: more expensive liquefied gas will stop the growth of pipeline gas supplies to Europe, but its export to China will increase (see Fig. 7). As a result, gas export revenue will increase by 12–13% with a decrease by 2040 in total revenues from fuel exports by 14% in the conservative and by 31% in the innovative scenarios, mainly due to a drop in oil export revenues (Table 3).

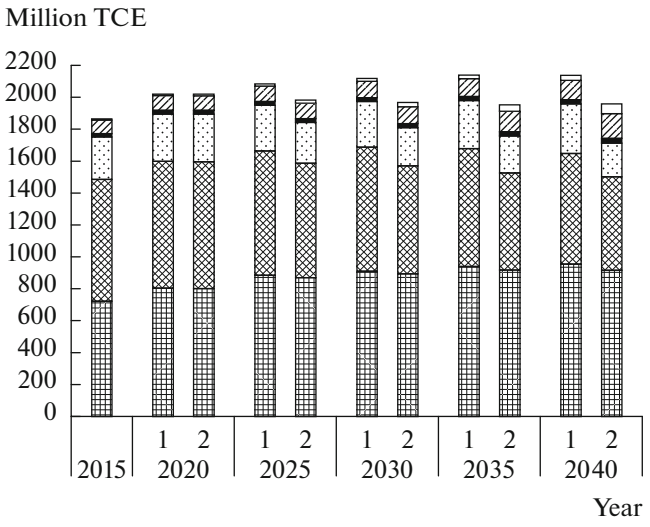

Fig. 8. Primary energy production in the conservative (1) and innovative (2) scenarios: ▦ gas; ▩ oil and products; ⬚ coal; ■ hydropower, ▨ atomic energy; □ NRES. Source: author's calculations.

Primary energy production. The production of primary energy in Russia to meet domestic demand and export needs will increase in the conservative scenario by 2030 by 14% and then stabilize. In the innovative scenario, the energy production will reach its maximum already in 2020 (8% higher than in 2015) and will decrease slightly by 2040 (Fig. 8).

This will not only bring Russia closer to the developed economies, but also mark the transition of the domestic energy to a new development stage – from quantitative growth to qualitative improvement. The reason is not the exhaustion of fuel resources, but an almost twofold slowdown in the growth of primary energy consumption in the innovative scenario for the development of world energy [1].

Oil and gas will remain the basis of the Russian energy sector, but their share in energy production will decrease from 80% in 2015 to 78–79% in both scenarios in 2040. However, oil dominance (41% in 2015 with a 39.5% share of gas) will be replaced by environmentally friendly natural gas. Its share in the production of primary energy will increase to 46–48% in 2035–2040. The share of solid fuel in the conservative scenario will remain in the range of 14–15%, and in the innovative scenario it will decrease to 11% by 2040. Scenarios for the development of the fuel industries in Russia for this period and the required new field development, fuel processing and transportation technologies are considered in [8–10].

Carbon-based energy will be replaced by noncarbon fuels: hydropower, NRES and nuclear energy, whose share in the primary energy production will

Table 4. The role of the fuel and energy complex in macroeconomic indicators of Russia under the conservative (1) and innovative (2) scenarios

Indicator	2015	2020	2025	2030*	2035*	2040*
Value added in FEC, billion USD**						
Scenario 1	295.5	307	407	418	445	413
Scenario 2		292	375	367	372	349
Scenario 1		104	138	141	151	140
Scenario 2, the same, % by 2015	100.0	99	127	124	126	118
Scenario 1		22	21	20	20	18
Scenario 2, FEC share in country's GDP, %	22.7	21	19	16	15	14
Contribution of the FEC to the consolidated budget, billion USD**						
Scenario 1		243	255	261	278	259
Scenario 2	152.2	227	217	224	227	209
Scenario 1		160	168	172	183	170
Scenario 2, the same, % by 2015	100	149	143	147	149	137
Scenario 1		34	26	27	25	24
Scenario 2, FEC share in the budget, %	26.4	29	24	22	21	19

* Average for five years.
** USD 2016Sources: [5, 8–10].

increase from 5% in 2015 to 7% in the conservative and 11% in the innovative scenario in 2040. At the same time, the share of NRES in the primary energy production will increase from 0.4% in 2015 to 1.4 and 3%, respectively, at the end of the period.

Direct impact of technological progress in the energy sector on the Russian economy. The volume of the energy value added by the fuel and energy complex (in consumer prices) will increase by 40% by the conservative and half as much as the innovative scenario (Table 4) by 2040, and its share in the country's GDP will decrease from 23% to 18 and 14%, respectively. This marks the end of the dominance of the fuel and energy complex under the innovative scenario in the country's economy.

Along with an almost twofold increase in Russia's GDP growth rate (see Fig. 2), this is caused by a more significant decrease in the export revenue of the Russian fuel and energy complex (see Table 3) with the intensification of TP in the global energy sector.

A decrease in the role of the fuel and energy complex in the Russian economy is also shown by the dynamics of its contribution to the country's budget. In the conservative scenario, it will increase by 70% over the period, but the share in the budget will decrease from 26.4 to 24%, and in the innovative scenario it will increase by half, and its share will decrease to 19% (see Table 4).

The share of the oil and gas segment in the added value of the fuel and energy sector will increase from 94–95% in the period until 2020 to 98–99% in 2036–2040. At the same time, the share of the oil industry will decrease from 74% at the beginning of the period to 61% by the end of the period according to the conservative and 47% according to the innovative scenario, mainly due to lower prices and volumes of export and oil production. The share of the gas industry in the added value of the fuel and energy sector will double under the conservative and 2.5 times under the innovative scenario, with an increase to 51% at the end of the period. The dominance of the oil and gas segment in the budgetary payments will continue, with the decreasing share of the oil industry from 82% in 2015 to 75% in the conservative and 49% in the innovation scenario in 2040 with a growth in the share of the gas industry to 24 and 34%, respectively.

Multiplicative effects of technological progress in the energy sector for the growth of the Russian economy[9]. Along with a direct contribution to the development of the Russian economy, the energy sector has a large indirect effect mainly through the dynamics of fuel and energy prices for consumers (this is the whole economy) and the volume of capital investments in the production and use of energy resources.

Scenario differences in the dynamics of external (see Table 1) and internal (see Table 2) *fuel prices* are directly taken into account in calculation of the contribution of the fuel and energy complex added value to the country's GDP (see Table 4). Their influence on the rest of the economy was determined using an interindustry development model of the Russian economy [11].

[9] The section was prepared in liaison with V. A. Malakhov.

Table 5. Change (relative to the conservative scenario) of the country's GDP growth with the intensification of technological progress in the energy sector in the world and Russia, %

Factor	2017–2020	2021–2025	2026–2030	2031–2035	2036–2040	2017–2040
Decline in fuel exports	0.4	–6.5	–2.1	–0.6	1.3	–10
Decrease in world fuel prices	–3.6	–3.7	–0.4	–1.1	–1.8	–14
Rising domestic fuel and energy prices	–0.2	–12.6	0.2	–2.6	–3.1	–25
Energy saving intensification	1.9	6.1	10.3	12.1	14.0	68
including:						
investment growth	1.6	4.4	7.0	6.6	7.4	41
Decrease in capital investments in the fuel and energy complex	0.2	–2.9	–1.0	0.3	1.8	–2
Total factors	–1.3	–19.6	7.0	8.1	12.3	17

Source: [12].

The implementation of the innovative scenario requires almost to double the country's average natural gas prices by 2030, followed by a moderate increase in the foreign market prices (see Table 2). A direct consequence of this, as rightly noted in [7], will be a slowdown in the growth of the produced GDP by other types of economic activity, which in our calculations will be 24–25% for the period (Table 5).

But the increase in gas prices intensifies technological and product-based energy savings (see Fig. 3) in all economy sectors, especially in electricity and heat generation [6]. These measures will require a *multiple increase in capital investments in the consumer energy sector*. Their amount per unit of energy saved acceptable for consumers cannot exceed investments in the production and delivery of energy resources to consumers. Since the main increase in the country's energy consumption until 2040 will be provided by natural gas, the difference between the scenarios in terms of the investments in the gas industry over the five-year periods is accepted as the upper margin for calculating the specific investment in technological and product energy saving in all sectors of the economy.

The amount of *investment in energy saving* determined under these conditions will increase by 2.8 times according to the conservative and almost 9 times according to the innovative scenario and at the end of the period will amount to 60% and 235% of direct investments in the development of the fuel and energy complex (Table 6). As shown in [12], the impact of this factor under the innovative scenario will increase 1.4 times over the period, the amount of added value in industries ensuring the modernization of the consumer energy sector. Taking into account the reduction (due to the energy saving) of specific intermediate consumption, GDP growth will be 88% and almost three times compensating the national economy for losses from the accelerated fuel and energy price increase.

A different situation occurs in the dynamics of *investments in fixed assets of the fuel and energy complex*. Due to the increasing complexity of subsurface and transport conditions for the extraction of fossil fuels and the high capital intensity of growing noncarbon energy, the volume of capital investments in the fuel and energy complex will increase under the conservative scenario. The decrease in primary energy production under the innovative scenario after 2020 (see Fig. 8) will require an increase in investment of half as much. The share of the fuel and energy complex in the country's total investments in fixed assets will continue to grow, from 24.4% in 2015 to 36% in the conservative and 29% in the innovative scenario in 2040 (Table 6).

The investments in the fuel and energy sector are dominated by the oil and gas segment: 85% at the beginning of the period, with a decrease towards the end to 77% under the conservative and 70% under the innovative scenario. In the conservative scenario, with an increase in the share of the oil industry in the total investments in the fuel and energy sector (51% in the first and 55% in the last five-year period), the ratio between the gas industry will change: its share will decrease from 34 to 20% and the share of the electric power industry in the fuel and energy investments will increase from 12 to 20%. In the innovative scenario, these processes will accelerate: the share of investments in electricity and heat production will increase to 29% while reducing the share of not only the gas (from 35 to 29%), but also the oil (from 50 to 41%) industries. The reason will be not only an accelerated increase in power generation capacity, but the change in its structure: fossil-fired power plants will be replaced by more capital-intensive noncarbon energy production [5].

Table 6. Capital investments in the development of the Russian energy sector under the conservative (1) and innovative (2) scenarios

Indicator	2015	2020	2025	2030*	2035*	2040*
Investments in fixed assets of the fuel and energy complex, billion USD**						
Scenario1		68	67	89	110	115
Scenario 2	67.5	69	67	77	85	92
Scenario 1		101	99	132	162	170
Scenario 2, the same, % by 2015	100	103	99	114	126	136
FEC share in the country's investments,%						
Scenario 1		23	22	29	35	36
Scenario 2	24.4	24	22	25	27	29
Investments in energy saving, billion USD**						
Scenario 1		14	39	45	55	67
Scenario 2	24	20	66	115	165	215
Scenario 1		57	162	188	229	279
Scenario 2, the same, % by 2015	100	85	273	480	687	894
Total investments in the energy sector of Russia, billion USD**						
Scenario 1		82	106	134	165	182
Scenario 2	91.5	90	132	192	250	306
Scenario 1		90	116	146	180	199
Scenario 2, the same, % by 2015	100	98	144	210	273	335

* Average for five years.
** USD 2016.
Sources: [5, 8–10].

CONCLUSIONS

The technological transition of the world energy from the dominance of fossil fuels to noncarbon energy threatens Russia with the decrease in fuel exports by 16% (relative to existing trends) by 2040 and by 8% in primary energy production. In general, over the period this can reduce the value added of the fuel and energy complex by a quarter and another 2–3% of the sectors that ensure its development.

The imperfection of the institutional environment in the country and the high cost of borrowed capital hinder investment in the economy and, together with the price freeze for natural gas (hence, power plant coal), actually block technological progress in the part of Russia's energy sector that is working on the domestic market. The calculations according to the innovative scenario showed that if the cost of borrowed capital is below 6% per year and the almost twofold increase in domestic gas prices (see Table 2), the growth of technological[10] and productive energy saving by 2.7 times will become economically justified by 2040. The achieved reduction in energy consumption in the country, will more than compensate for the negative consequences of rising domestic prices for fuel and energy.

In addition, capital investments in energy saving will be five times higher than the reduction in investment in the fuel and energy sector under the innovative scenario relative to the conservative one. The need for tangible embodiment of these investments will accelerate from the mid-2020s the development of industries that modernize the energy consumer sector, and their added value will increase by 41% over the period.

The implementation of the considered factors will accelerate the growth of Russia's GDP to 2.5–2.8% in the 2020s and to 3% after 2030 [12] despite the fact that the source work for this study [1] predicts (based on forecasts [13]) a slowdown in the global GDP growth from 2.9% in 2025–2030 to 2.3% in 2035–2040.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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