MACROECONOMIC IMPACT OF THE ENERGY TECHNOLOGIES CHANGES IN RUSSIA: INPUT-OUTPUT APPROACH

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Abstract

The world energy sector is dynamically transforming under the influence of new technologies in the fields of road transport, electricity generation, energy efficiency, digitalization and automation. The spread of new technologies leads to changes in the structure of energy resources and construction materials consumption, trade and anthropogenic emissions. This means a large-scale change in the structure of cost and value added in the economy. This research problem is strongly relevant for Russia, since a significant share of exports and budget revenues are provided by the national energy sector, which is based on fossil fuels. The adaptation to the world energy sector transformation is of high priority for the Russian economy.

Keywords: input-output, input-output coefficients, renewable energy, electric cars, technology, Russian economy, IPCC, global warming, energy balance

Overview

One of the key issues in input-output (IO) approach is the dynamization of input-output (technical) coefficients matrix. Obviously, change of IO coefficients can significantly affect both dynamic and structural characteristics of the economy in long-term. This is IO coefficients modeling that allow to use known technological proportions in macroeconomic calculations. With such tool developed, calculations on interindustry macrostructural models can be the core of technological forecasting.

In Russia, interindustry models that contain a unit for calculating IO coefficients are called Interindustry Interaction Models. The most famous one was developed in the 1980s by Institute of Economic Forecasting of the Russian Academy of Sciences (IEF RAS) and was used as a tool for making the Integrated Program of Scientific and Technological Progress of Russia. This model had not only calculating units for final demand and value added, but also included more than 100 equations for the most important IO coefficients.

The main constraint for IO coefficients modelling is the need to have input-output tables in constant prices for a relatively long retrospective period. As far as we know, the official series of input-output tables are made only in Japan. Researchers from other countries have to build estimated tables (most often it is done by defiling rows of table with industry output deflators).

However, the lack of long comparable data series remains. In total, there are reliable and comparable input-output tables only for a few large countries.

Under these conditions, the econometric estimation of IO coefficients is extremely difficult, but this does not mean that structural and technological modeling is an unsolvable task.

In principle, there are two perspective alternatives to the regression calculation of IO coefficients.

The first is by using the proportion of costs relevant for different technological stages. This approach is well suited for developing countries. Comparing the current technological structure with some reference developed country, we can set the trajectory of IO coefficients changing provided that we have a symmetric IO table in the product-to-product logic.

The second alternative includes using the additional units that describe technological processes much better than input-output tables do.

The second approach may be based on the existing system of goods balances. Currently, the most important IO coefficients are associated with the processes of energy use. Relevant energy balances are being developed by both national statistical services and international agencies. In the Russian Interindustry Model (RIM), we use energy balances developed by the International Energy Agency (IEA) as the most methodologically appropriate for the structure of the input-output tables.

Thus, fundamentally we can distinguish three main approaches to IO coefficients modeling in the framework of interindustry macroeconomic models:

1) econometric: used in modeling flows, which are mainly determined by intra-economic interaction. Requires the high quality and long series of statistical data;
2) balance: assumes direct and inverse interaction of IO tables with additional product balances;
3) technological: based on the use of cost proportions determined by particular technological processes. This approach can be used for product-to-product type IO tables and involves a detailed study of technologies parameters.

All the approaches described were used in the RIM model, including the modelling of IO coefficients associated with the development of energy sector.

Methods

RIM model

Russian Interindustry Model (RIM) is developed for medium- and long-term calculations. The model uses 44-industries classification in the product-to-product logic. The model belongs to the Inforum[1] type model family. It involves the econometric estimation of the second and third quadrants' elements in symmetrical IO table.

The data source is the series of IO tables in constant and current prices for 1980-2015 developed by M. Uzyakov. IO tables are consistent with the system of national accounts.

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[1] http://www.inforum.umd.edu

The model also contains expenditure and income balances of the population, government finance, demographic balance with a detailed age and sex structure, balance of payments, monetary and financial accounts, trade balance, data on sectoral employment, capital balance.

Calculation is based on identities of the classical Leontief model:

$$output = A * output + fd \tag{1}$$

$$fd = pce + gov + inv + invn + ex - im \tag{2}$$

$$va = tax + taxop + wagesal + mixed + profit \tag{3}$$

$$p*A * output + va = p * output \tag{4}$$

where

output is output vector by industry;

A is matrix of IO coefficients;

fd is final demand matrix by industry

pce is vector of households final consumption by industry;

gov is vector of government expenditures by industry;

inv is vector of capital expenditures by industry;

invn is vector of changes in inventories and valuables by industry;

ex is exports by industry;

im is imports by industry;

va is value added matrix by industry;

tax is vector of net taxes on products by industry;

taxop is vector of net production taxes by industry;

wagesal is vector of wages by industry;

profit is vector of net profit and depreciation by industry;

mixed is vector of gross mixed income by industry;

p is vector of prices by industry.

The concept of the model reflects real business cycle. The model presents both the production in real terms and the formation of income in nominal ones. Production and distribution of products, final demand and supply are calculated at constant and current prices, while income and its distribution are calculated only at current prices.

For each year, the elements of final demand (in nomenclature of (2)) by industry at constant prices are calculated using econometric equations. Further, output by industry is calculated according to (1). Further, on the basis of output and fixed capital, the number of people employed is calculated by industry. On this step from real terms we turn to indicators in nominal values, namely to the income and sectoral prices. First, all the components of gross value added by industry are calculated in the nomenclature of (3). Second, the sectoral prices are calculated in accordance with the Leontief price model (4).

Elements of value added matrix act as indicators of economic subjects incomes: population, state and business. Within the framework of the income distribution unit, a transition is made from the nominal incomes and sectoral price indices to the final demand at constant prices, thereby looping the calculation procedure. The calculation process is repeated until the conditions of convergence are satisfied. After convergence has been reached, the transition to the next forecast year is carried out.

The rigidity of the model is achieved by the fact that each element of final consumption is associated with particular balance parameters. As a result, the growth of both demand and supply is always limited with the corresponding resource potential of the economy. On the production side, one of the most important constraints is fixed capital (production capacity) which is calculated through investments. At the same time, incomes of economic agents restrict their consumption.

The detailed description of RIM model can be found in publications [1,2].

Improvement of the RIM model for structural and technological estimations

Currently IEF RAS improves the RIM model adding the strong connections between IO tables, energy balances and unit of technological processes. The interactions of these elements are shown in Figure 1. The main purpose is to make IO coefficients dynamic.

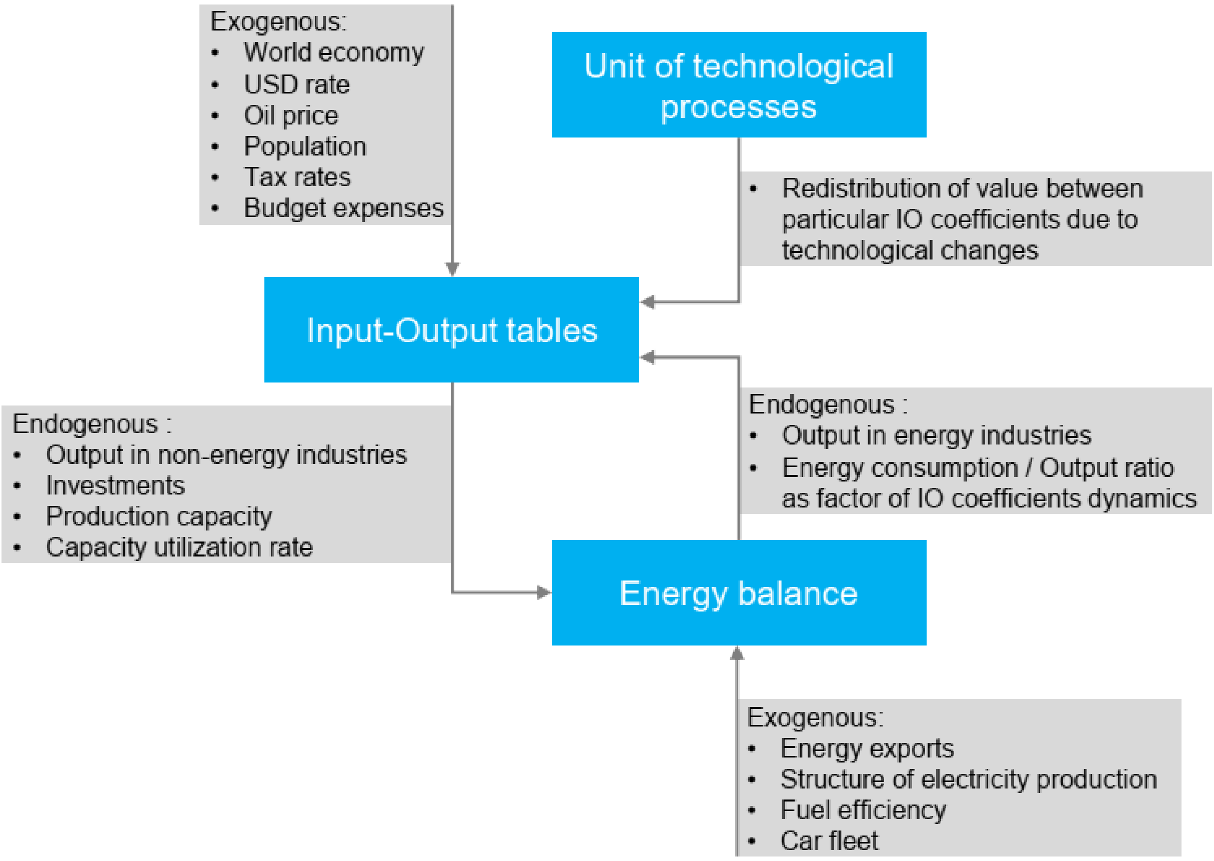

Figure 1. Interactions between input-output tables, energy balance and unit of technological processes in the RIM model. Source: IEF RAS

Let's consider the interaction between IO table and energy balance. The concept is to calculate energy consumption in industries of Russian economy taking into account its output and also energy efficiency processes.

On the first step we calculate the specific energy consumption in industries for the retrospective period:

$$eff_{im} = e\_cons_{im} / output_i \tag{5}$$

where

eff_{im} is specific consumption of energy resource m in industry i;

e_cons_{im} is consumption of energy resource m in industry i;

$output_i$ is output in industry i.

On the second step we perform regression estimation of eff_{im} as a function of investments, production capacity, capacity utilization rate and a few other parameters (in the final equation we include only those parameters that are significant):

$$eff_{im} = \mathrm{F}(inv_i, cap_i, capeff_i) \tag{6}$$

where

inv_i is investments in industry i;

cap_i is production capacity of industry i;

$capeff_i$ is capacity utilization rate in industry i.

Basing on these functions F we make the forecast of energy consumption:

$$f\_e\_cons_{im} = eff_{im} * f\_output_i = \mathrm{F}(f\_inv_i, f\_cap_i, f\_capeff_i) * f\_output_i \tag{7}$$

where prefix f means the forecast value.

Received estimations of eff_{im} are important for two reasons. First, we can calculate the production in energy industries taking into account domestic consumption and net exports. This is the indicator for output dynamics of appropriate energy industries in IO table (e.g. mining or electricity production). Second, and the most important, we use eff_{im} as indicator of particular IO coefficients dynamics. For instance, having specific electricity consumption in metallurgy estimated, we can make regression estimation of IO coefficient representing the flow of industry "Electricity, gas, steam and air conditioning supply" to industry "Manufacture of basic metals":

$$a_{em} = \mathrm{F}(eff_{me}) \tag{8}$$

where

eff_{me} is specific electricity consumption in metallurgy;

a_{em} is IO coefficient representing the flow of industry "Electricity, gas, steam and air conditioning supply" to industry "Manufacture of basic metals".

We perform such calculation for each pair of energy resource and industry in model provided their value is significant.

The logic of interaction between IO tables and unit of technological processes is described further.

Macrostructural changes due to the development of new technologies in the field of transport

Structural and technological changes in the transport sector are expected to be associated with a gradual increase in the fleet of road vehicles that consume electricity as a fuel, automating and digitizing transport services, and using advanced construction materials. Such scenario will have a number of effects that can be expressed through the value redistribution of the IO coefficients in the input-output tables.

1. Changes in the structure of household consumption associated with the spread of personal electric vehicles

The most obvious effect of the personal electric cars spread is the redistribution of households' expenses from the petroleum products (gasoline, diesel fuel) to electricity. Meanwhile, it should be taken into account that households consume oil products not only as fuel for passenger cars. This thesis is even more relevant with regard to electricity, since currently people use it in everyday life, while charging of electric cars is still insignificant.

If we consider the total amount of electricity and petroleum consumption by households in different countries, it turns out that share of domestic electricity use acounts for 18-22%; non-fuel use of petroleum products accounts for 2% in the USA, 9% in the EU, 11-12% in Russia and China, and reaches significant 21% in India. And the use of petroleum products as a fuel for personal cars accounts for 61-78%. So, the latter is the energy demand which electric cars will compete for with the traditional cars on internal combustion engines (ICE).

In terms of the input-output approach, this redistribution refers to the household consumption column. Namely this means a reduction in coefficient indicating the share of industry “Manufacture of refined petroleum products and coke” in the structure of households' costs and an increase in coefficient of industry “Electricity, gas, steam and air conditioning supply”.

2. Changes in the cost structure of industry “Manufacture of motor vehicles, trailers and semi-trailers”

A number of effects are concentrated within the industry "Manufacture of motor vehicles, trailers and semi-trailers".

First, the technology of electric vehicles is based on the use of electric motors powered by electricity stored on board the car. Therefore, at the stage of production of motor vehicles, there is a redistribution of costs associated with the driving system of ICE technology (the engine itself and the fuel system) to the costs associated with the acquisition of electric storage batteries. In terms of input-output approach, this means a decrease in the diagonal IO coefficient of industry "Manufacture of motor vehicles, trailers and semi-trailers" and an increase in the IO coefficient indicating the consumption of industry "Manufacture of motor vehicles, trailers and semi-trailers" of products created in industry “Manufacture of electrical equipment”.

Second, we observe the evolutionary expansion of automating vehicle control systems, which leads to an increase in the IO coefficient indicating the consumption of industry “Manufacture of motor vehicles, trailers and semi-trailers” of products created in industry “Manufacture of computers, electronic and optical products”.

Third, we can see the common existing shifts in the constructional materials use, namely, from metals to plastics and composites. This means a decrease in the IO coefficient indicating the consumption of industry "Manufacture of motor vehicles, trailers and semi-trailers" of products created in industry “Manufacture of basic metals” and an increase in the IO coefficient showing the demand for goods of industry “Manufacture of rubber and plastic products”.

3. Particular changes in the materials consumed for the electric cars production

The driving part of traditional ICE cars consists of the engine itself, fuel storage and supply systems, and exhaust gases. All these parts are produced mainly from the ferrous metals. The use of non-ferrous metals in a traditional car is mainly due to the goals of reducing the overall weight of the vehicle and, accordingly, fuel consumption. Each kilogram of aluminum used reduces the total weight of the vehicle by one kilogram. Therefore, an increasing number of automotive parts are produced from aluminum nowadays: engine cooling radiators, rims, bumpers, suspension parts, engine cylinder blocks, transmission bodies and, finally, body parts such as bonnets, doors and even the entire frame. As a result, since the 1970s, the quantity of aluminum in the car increased from 35 kg to today's 152 kg (about 8% of the total weight) [3].

However, in an electric car the structure of the materials used is significantly different (Table 1)[2]. Firstly, the weight of the vehicle itself is higher due to the heavy battery (540 kg in Tesla Model S). Secondly, the engine weight in an electric car is lower than it is in a traditional ICE car. Thirdly, up to 80% of the battery weight can be attributed to non-ferrous metals (they are used for energy cells constructing), while ferrous metals are used only in order to produce the serving parts of the battery. There is also a small-scale use of copper in the engine. In addition, the consumption of aluminum in the electric car’s body is generally higher in order to reduce its weight. In total, about 37% of the electric car’s weight can be attributed to the consumption of non-ferrous metals.

Table 1. The weight structure of ICE and electric cars

	Tesla Model S	BMW 5
Total weight, kg	2241	1810
Ferrous metals	1280	1558
Non-ferrous metals	838	152
Other materials	123	100

Source: IEF RAS, [4]

In the framework of the input-output methodology, the production of internal combustion engines refers to the output of industry “Manufacture of motor vehicles, trailers and semi-trailers”, and the production of electric batteries refers to the output of industry “Manufacture of electrical equipment”. Thus, there will be a reduction in the IO coefficient showing the demand of industry “Manufacture of vehicles, trailers and semi-trailers” for products of industry “Manufacture of ferrous metals”, as well as an increase in coefficient of industry “Manufacture of electrical equipment”. At the same time the IO coefficients indicating the consumption of industry “Manufacture of electrical equipment” of products created by industries “Manufacture of ferrous metals” and “Manufacture of non-ferrous metals” should increase. The proportion shown in Table 1 can be used for such modeling purposes.

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[2] The estimates shown in Tables 1-2 were made with the strong participation of Alexander Galinger (IEF RAS).

However, the effects for such a redistribution can be calculated only if there are detailed input-output tables, where industries “Manufacture of ferrous metals” and “Manufacture of non-ferrous metals” are separated. IEF RAS has such tables for Russia.

Macrostructural changes due to the development of new electricity generation technologies

Structural and technological changes in the electricity production are expected to be associated with the spread of solar and wind energy. Since natural-gas-based electricity generation dominates in Russia, the parameters of solar and wind power plants are compared with the gas ones.

1. Operational stage

At the stage of operation, a feature of generating equipment based on renewable energy is the absence of fuel consumption. Therefore, if the renewable-based generation replaces gas power plants, the replaced volume of gas consumption in the industry “Electricity, gas, steam and air conditioning supply” will disappear in all subsequent years. In fact, this will cut GDP, since the industry “Production of natural gas” will generate less revenue. Theoretically, with the widespread use of renewable energy in the long-term period, the price of electricity may decrease due to lower operating costs, which will create a positive effect on economic growth. However, the practice of using renewable energy leads to opposite results for now [5].

2. Investment stage

The most differences concern the investment stage (Table 2). Key characteristics of renewable energy sources are a) low energy density, b) low utilization rate of the power capacity (for example, in Russia natural-gas-based capacity is used 4000 hours per annum, while wind-based capacity operates 2000 hours, and solar-based capacity works only 1000 hours), c) relatively short lifetime (estimated at the level of 25 years). As a result, in order to produce the same amount of electricity the country will have to build much more power capacity based on renewable energy sources compared to natural gas technology.

Table 2. The materials use in the power plants construction (investments stage) in order to produce 1000 GWh of electricity per annum, th ton

	Solar	Wind	Natural gas
Concrete (base)	1011.0	280.6	18.1
Concrete (tower)		99.8	
Silicon	669.7		
Steel, iron	222.6	15.5	8.1
Copper		0.4	0.1
Polymers		5.2	
Composites		19.9	
Electronics	8.8	6.5	0.5
Total weight	1912.1	427.8	26.7

Source: IEF RAS, [6, 7]

The spread of renewable energy leads to a sharp increase in demand for concrete, metals, silicon, as well as increased use of composite materials. Consequently, in the end it means the higher output of industries “Manufacture of other non-metallic mineral products”, “Manufacture of basic metals”, and “Manufacture of chemicals and chemical products”. One can model it through an increase in the share of these industries in the structure of capital expenses of industry “Electricity, gas, steam and air conditioning supply" using the proportions shown in Table 2.

Results

We consider the impact of IPCC Global Warming of 1.5 ºC Scenario [8] implementation on the Russian economy in this chapter. In addition, the estimations of structural macroeconomic changes due to new energy-related technologies spread in Russia are shown.

IPCC Global Warming of 1.5 ºC Scenario. Impact on the Russian Economy

The implementation of the IPCC scenario assumes an accelerated spread of low-carbon energy technologies. This primarily concerns electric power industry (replacement of carbon-containing fuels like coal and natural gas with solar, wind, hydro, and nuclear energy), as well as road transport (replacement of carbon-containing motor fuels with electricity).

The key factors influencing on the Russian economy under IPCC scenario are as followed:

- reduction of Russian hydrocarbons exports (oil and petroleum products, natural gas, coal);
- large-scale increase in investment in the renewable-based electric capacities;
- higher electricity prices due to the need of financing investments in renewable energy sources.

Under IPCC scenario, the share of renewable energy (solar, wind and hydro) is assumed to reach up to 70% in the structure of global electricity generation by 2045, and the shares of coal and natural gas are considered to fall to 2% and 11% respectively. In addition, the share of electric vehicles should rise to 50% of the world fleet.

The key indicators of the Russian energy sector corresponding to the IPCC scenario are presented in the Table 3.

The main impact is the decrease in production of oil (by almost 27% in 2045 compared with Reference scenario), natural gas (by 34%) and coal (by 58%), due to a lower global demand for these energy resources. Reducing hydrocarbon production will require significantly less investment (by 21% in 2030 and 41% in 2045). Due to these factors, under the IPCC scenario, the Russian GDP will be 8% lower by 2045 compared with Reference scenario (with taking into account interindustry interactions).

A feature of renewable energy projects is their high capital intensity. According to information provided by the company Rosnano, which is engaged in the development of solar generation in Russia, 1 kW of installed solar and wind capacity requires about 95-100 thousand rubles nowadays, though this indicator is expected to fall to 91-93 thousand rubles by 2025 and 76-83 thousand rubles by 2035. In addition, the utilization rate of solar power plants is only 13%. As a result, it takes much more renewable-based capacity to meet the same demand (compared to the Reference scenario based on gas generation with utilization rate of about 50%).

At the same time, the largescale spread of electric transport will provide additional demand for electricity, which must be met with higher capital intensity.

Table 3. Key indicators of the Russian energy sector development under the IPCC Global Warming of 1.5 ºC Scenario

	2015	2020	2025	2030	2035	2040	2045
Oil production, mta							
Reference Scenario	534	555	578	598	615	624	630
IPCC Scenario	534	554	562	541	526	497	459
Natural gas production, bcm							
Reference Scenario	634	747	768	787	804	819	832
IPCC Scenario	634	702	680	651	622	595	552
Coal production, mta							
Reference Scenario	373	466	560	560	560	560	560
IPCC Scenario	373	406	403	370	325	277	234
Electricity production, TWh							
Reference Scenario	1066	1155	1180	1205	1230	1255	1280
IPCC Scenario	1066	1177	1261	1331	1400	1475	1553
Solar and Wind share in electricity production							
Reference Scenario	0%	0.1%	0.5%	1%	3%	4%	6%
IPCC Scenario	0%	1%	6%	17%	28%	39%	50%
Electric cars share in the cars fleet							
Reference Scenario	0%	0%	0%	0.2%	1%	2%	4%
IPCC Scenario	0%	4%	12%	18%	28%	39%	49%
Investments in oil, gas and coal production, bln rubles (constant prices of 2017)							
Reference Scenario	1808	2105	2546	2832	3115	3323	3456
IPCC Scenario	1808	2040	2233	2226	2179	2108	2034
Investments in electricity production, bln rubles (constant prices of 2017)							
Reference Scenario	339	375	402	428	455	482	508
IPCC Scenario	339	373	2350	2559	2594	2666	2709

Source: IEF RAS

Interestingly, under the IPCC scenario the growth in investments needed for the electricity supply industry is comparable with the reduction in investments of hydrocarbon production industry. This property partially eliminates the damage to Russian GDP from green technologies spread[3], especially if the construction of renewable energy capacities will be based on Russian domestic supply. An increase in output and investment in the electric power industry will make it possible to cut the loss of Russian GDP in 2045 to only 3.5%.

Russia practices feed-in tariff type mechanism for financing investments in the power industry. Therefore, the need to finance large investments in renewable energy capacities leads to a significant rise in electricity prices. Our estimates show that the IPCC scenario will require 40% higher electricity prices than they could be under the Reference scenario. At the same time, with

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[3] However, an important question remains. Russia is currently exporting hydrocarbons, receiving income from the world market. This is the place of Russia in the global system of international labor distribution, thanks to which the country receives additional external financial resources. But can Russia find its place in foreign markets even with a competitive supply of renewable energy? This is a very controversial topic. Basing only on the domestic market, the Russian green energy industry will not be able to compensate possible loses of hydrocarbon exports.

an increase in electricity prices by 10%, Russian GDP decreases by 0.4%. Thus, the additional loss of GDP will be about 1.6% under the IPCC scenario.

Figure 2 shows the factor analysis of changes in the average annual GDP growth rate in Russia in the period up to 2045 in case of IPCC scenario implementation.

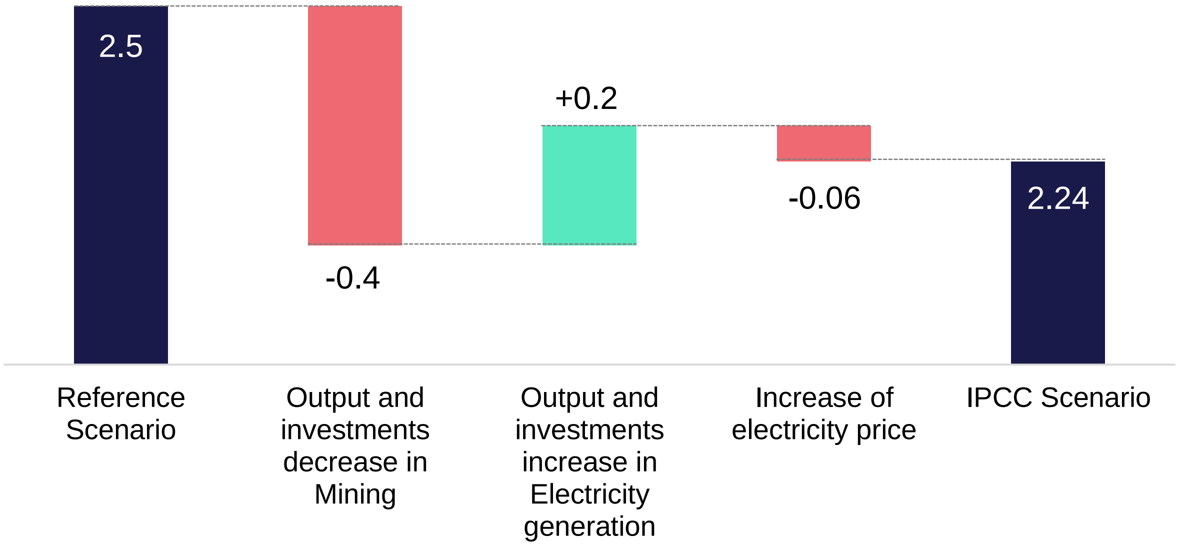

Figure 2. Factor analysis of changes in the average annual GDP growth rate in Russia in the period up to 2045 in case of IPCC scenario implementation, in percentage points.
Source: IEF RAS

The average annual growth rate of Russian GDP in the Reference scenario is estimated as 2.5%. Reducing output and investment in oil, gas and coal production will result in a drop of 0.4 percentage points. The increase in output and investment in power sector will provide additional 0.2 percentage points. Rising electricity prices will be a negative factor and will reduce the average annual growth rate of GDP by 0.06 percentage points. In total, in the IPCC scenario, GDP growth will slow down to an average of 2.24% per year.

Macrostructural shifts due to the technological changes in the Russian economy

Another interindustry estimation area in IEF RAS is the macrostructural shifts due to the technological changes. Currently we are considering the following factors:

- the spread of low-carbon energy technologies (the effects are described above in the Methods chapter);
- digitalization and automation of the economy: they lead to an increase in the quality of management, which means a relative decrease in the specific level of trade and transport margins, with an increase in the specific expenses to IT and financial services in almost all industries. In addition, these processes mean an increase in demand for computing power;
- structural change in the complex of construction materials: a significant part of the effects is formed in machinery sector, where the processes of gradual replacement of ferrous metals by non-ferrous metals and chemicals (composite materials) occur;

- decrease in demand for personal transportation due to the development of transport-sharing use practice (carsharing, taxi, public transport, bicycle and scooter rental), as well as potential reduction in people mobility due to the overall digitalization of the economy.

Macroeconomic effects of considered technological changes are shown in Table 4[4].

Table 4. Output growth in the industries considered due to technological changes in 2040 (compared to the scenario with the current technological structure)

Industry	Growth in 2040
Telecommunications	229%
Manufacture of rubber and plastic products	150%
Manufacture of computer, electronic and optical products	112%
Manufacture of other non-metallic mineral products	110%
Electricity, gas, steam and air conditioning supply	106%
Land transport and transport via pipelines	106%
Manufacture of chemicals and chemical products	106%
Manufacture of electrical equipment	105%
Manufacture of refined petroleum products and coke	94%
Manufacture of basic metals	93%
Wholesale and retail trade	90%
Manufacture of wood and products of wood	88%
Manufacture of motor vehicles, trailers and semi-trailers	82%
Total output	102%

Source: IEF RAS

The greatest impacts are associated with the process of digitization and automation: they are revealed in significant increase in output of the industry “Telecommunications” (by 129%) with simultaneous decrease in output of industry “Wholesale and retail trade” (by 10%). There is also additional output in the industry “Manufacture of computer, electronic and optical products” (by 12%) as a result of higher demand for calculating capacities.

The effects associated with changes in the use of construction materials are relatively high: the output growth in the industry “Manufacture of plastic products” reaches 50%. The output of the industry “Manufacture of chemicals and chemical products” is also growing by 6%. At the same time, there is output reduction in the industries “Manufacture of wood and products of wood” (by 12%) and “Manufacture of basic metals” (by 7%).

The spread of electric cars leads to smaller relative changes. Output of “Electricity, gas, steam and air conditioning supply” industry increases by 6%; output of industry “Manufacture of electrical equipment” increases by 5%; and output of “Manufacture of refined petroleum products and coke” may be 6% lower. However, there are few additional effects in the field of road transportation. Potential spread of sharing practices and reduction of people mobility leads to lower output in the industry “Manufacture of motor vehicles, trailers and semi-trailers” (by 18%) with simultaneous increasing the output of industry “Land transport and transport via pipelines” (by 6%). And the

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[4] The estimates shown in Table 4 were made with the strong participation of Sergey Milyakin (IEF RAS).

widescale construction of renewable-based capacities provides significant increase in the output by “Manufacture of other non-metallic mineral products” (by 10%).

Thus, technological changes create a positive impact on some industries and a negative one on others. The cumulative output of the Russian economy may increase by 2%.

On the one hand, small cumulative result is logical, as huge and complex objects (for example, GDP, output, energy consumption) are strongly inertial, since multidirectional factors simultaneously make impact on them, weakening the effect of each other. On the other hand, we are far from the final stage of RIM model development, so the results are to be adjusted.

Key conclusions

1. One of the ways to perform economic and technological forecast, taking into account the possible shifts in interindustry interactions, is to use the input-output approach, which ensures the harmonization of the dynamic and structural parameters of the economy development.

2. In order to model input-output coefficients combination of three methods can be used: econometric, balance and technological ones.

3. The modeling of input-output coefficients requires the system of developed dynamic interindustry models.

4. Only the most important input-output coefficients are usually the subject to modeling.

5. Scenario of aggressive carbon regulation, associated with the purpose to prevent the average global temperature from rising by more than 1.5 degrees, leads to slowdown in economic growth in Russia due to lower production and investment in the oil and gas industry. The growth in investments to power sector partially eliminates the negative impact. Nevertheless, the decrease in Russian GDP growth rate can account for 0.3 percentage points in the period up to 2045.

6. Scenario of technological changes in the energy sector leads to significant shifts in the production structure of the economy but is characterized by relatively weak impact on the total output.

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