Contribution assessment of a technological factor to reducing CO_2 emissions in Russia

Vasily Nemov[1,2], *Irina* Filimonova[1,2, *], *Mikhail* Mishenin [1,2] and *Ekaterina* Zemnukhova [1,2]

[1]Trofimuk Institute of Petroleum Geology and Geophysics SB RAS, 3, Koptug, 630090, Novosibirsk, Russia
[2] Novosibirsk State University, 1, Pirogova, 630090, Novosibirsk, Russia

Abstract. Currently, the economy should develop along an innovative way of development with an increase in the efficiency of the use of natural resources and a decrease in negative impacts on the environment to ensure stable economic growth and improve the quality of life of the population. The purpose of the study is to assess the environmental and energy effects that affect the environment and energy intensity in the country. The dynamics of greenhouse gas emissions in Russia are contemporaneously influenced by many different factors, such as the industry structure of the economy, the structure of the fuel and energy balance, the level of technological equipment, and the situation in world markets. Our analysis showed that the dynamics of CO_2 emissions in Russia are determined primarily by the growth rates of the population's well-being and by the growth of industrial production. At the same time, in the period 2000-2012, the effect of welfare growth was partially offset by a decrease in the energy intensity of the economy, but then the potential for reducing energy intensity due to changes in the structure of the economy was exhausted. The contribution of the technological factor is also insufficient. So for the period 2000-2017, the improvement of technologies in the field of heat and electric energy production from fossil energy sources made it possible to reduce CO_2 emissions by only 33 million tons. Another significant constraint to the transition to a low-carbon trajectory of development is the low rate of implementation of energy-saving technologies in the production of energy-intensive industrial products, maintenance of residential and public buildings.

1 Introduction

Currently, the economy should develop along an innovative way of development with an increase in the efficiency of the use of natural resources and a decrease in negative impacts on the environment to ensure stable economic growth and improve the quality of life of the population.

The most intensive period of growth in emissions of pollutants into the atmosphere was from 1990 to 2010. During this period, carbon dioxide emissions increased by more than 45% (9.7 billion tons). The Asia-Pacific region and the countries of the Middle East accounted respectively for 76% and 9% of the increase in emissions. At the same time, during the same period, CO_2 emissions in European countries decreased by 13.6%, and in Russia and the CIS countries - by 32%. However, for the CIS countries, this is not caused by an increase in energy efficiency, but by a decline in industrial production.

The growth of greenhouse gas emissions at a high rate in 1990–2010 is associated with a high rate of growth in energy consumption (mainly coal consumption) in developing countries. The growth in the population and prosperity of developing countries has been significantly offset by the decrease in the energy intensity of the economy and by the change in the structure of consumed energy towards the consumption of natural gas and alternative energy sources since the 2010s. As a result, the average annual growth rate of CO_2 emissions in the APR countries decreased from 4.9% in 1990–2010 to 2.3% in 2010–2018 [1-3].

Over the past four years, there has been acceleration in the growth of greenhouse gas emissions. The growth rate of emissions increased from -0.1% in 2015 to 2% in 2018. This fact is associated with an increase in the share of energy-intensive industries in the economies of China and the United States, which has increased the demand for energy resources. Climatic factors also had a significant impact on the dynamics of greenhouse gas emissions in 2018. For example, cold winters in the United States have led to an increase in energy consumption in winter and summer. As a result, after a period of emission reductions in 2015-2017, in 2018, CO_2 emissions increased by 115 million tons. In European countries, on the contrary, milder climatic conditions in 2018 led to a reduction in energy consumption in the energy sector and a reduction in greenhouse gas emissions by 69 million tons.

The dynamics of greenhouse gas emissions in Russia is simultaneously influenced by many different factors, such as the industry structure of the economy, the

---

* Corresponding author: filimonovaiv@list.ru

structure of the fuel and energy balance, the level of technological equipment, and the situation on world markets [4, 5].

Thus, the purpose of the study is to assess the environmental and energy effects that affect the environment and energy intensity in the country.

2 Data

The sources presented in table 1 became the information base for statistical calculations and factor analysis in the framework of our study.

Table 1. Database formation.

Data	Data source
Population size	Rosstat
Consumption of fossil fuels	BP
Real GDP	Rosstat
CO$_2$ emissions in Russia	Rosstat
	Roshydromet
	BP
	IEA
CO$_2$ emissions from burning fossil fuels	IEA

The study also used national-level documents - strategic, programmatic, and official documents of the government and relevant ministries.

3 Methodology

The IPAT model is the basis for the factor analysis of this research work. Using this model, we assessed the factors causing changes in the analyzed indicator of emissions that pollute the atmosphere. This is an identity that determines three factors of anthropogenic impact on the environment, and according to which the impact of humanity (I) is expressed as the multiplication of population (P), affluence (A) and technology (T):

$$I = P \times A \times T \tag{1}$$

The use of this formulation makes it possible to structure the analysis of the driving forces that underlie the dynamics of harmful emissions. Further, this identity is transformed in the following form:

$$CO_2 = POP \times \frac{GDP}{POP} \times \frac{EC}{GDP} \times \frac{CO_2}{EC} = G \times E \times CI, \tag{2}$$

where CO$_2$ is carbon dioxide emissions; POP is population; GDP is Gross Domestic Product; EC is total energy consumption; G is GDP per capita; E is energy intensity of GDP, or in other words, the technology of using energy to produce GDP; CI is the carbon intensity of energy produced, energy production technology. The latter two factors determine two aspects of technological change: energy efficiency and energy production technology.

The subsequent development of the methodology for factor analysis of anthropogenic carbon dioxide emissions made it possible to include in the analysis of the influence of changes in the structure of fossil fuel consumption. Thus, the amount of carbon dioxide emissions from the combustion of each type of fossil fuel is different, i.e. they have different emission factors. The rapid development of alternative energy with zero carbon dioxide emissions and its increasing importance in the structure of energy balances has led to the need for further improvement of the methodology. As a result, in 2008, a model was proposed that allows one to assess the effect of changing the share of energy not related to CO$_2$ emissions, such as nuclear, hydroelectric, solar, etc.

$$CO_2 = \sum_i POP \times \frac{GDP}{POP} \times \frac{EC}{GDP} \times \frac{FE}{EC} \times \frac{FE_i}{FE} \times \frac{CO_{2i}}{FE_i} = \\ = \sum_i^k POP \times G \times I \times S_1 \times S_{2i} \times F_i, \tag{3}$$

where CO$_2$ is carbon dioxide emissions, the summation is performed by types of fossil fuels used (i = 1, .., 3: oil, coal, natural gas); POP is the country's population; GDP is a gross domestic product; EC is the energy consumption of all types; FE - consumption of all types of fossil fuels; FE$_i$ - energy consumption of the i-th type of fossil fuel; CO$_{2i}$ - emissions from combustion of the i-th type of fuel; G - GDP per capita; I - energy intensity of GDP; S$_1$ - share of fossil energy carriers in total consumption energy; S$_{2i}$ is the share of the i-th type of fossil energy in the total consumption of fossil fuels; F$_i$ is the emission factor of the i-th fuel.

Thus, within the framework of the applied method, the dynamics of carbon dioxide emission is explained by the cumulative influence of the following factors:

- population dynamics ΔC_{POP}, representing the change in carbon dioxide emissions due to a change in population;
- welfare change ΔC_{GDP}, showing the change in CO$_2$ emissions associated with an increase or decrease in income;
- change in the energy intensity of GDP ΔC_{enint}, which characterizes the change in the sectoral structure of the economy and the level of efficiency in the use of energy resources;
- change in the share of fossil energy carriers ΔC_{renew}, which characterizes the contribution of alternative and renewable energy to the reduction of carbon dioxide emissions;
- changes in the structure of consumption of fossil energy carriers ΔC_{FF}, which characterizes the impact of inter-fuel competition (for example, coal substitution with gas) on the volume of greenhouse gas emissions;
- a change in fossil fuel combustion technology $\Delta C_{carbint}$, which shows the change in the volume of carbon dioxide emissions due to a change in the specific carbon dioxide emissions when burning a kilogram of fossil fuels.

n this paper, the determination of the contribution of each factor to the dynamics of carbon dioxide emissions

will be calculated based on the decomposition of changes using the log average of the Division's index.

$$\Delta C_{POP} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln(POP_t/POP_0), \quad (4)$$

$$\Delta C_{GDP} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln\left(\frac{GDP_t}{POP_t}\Big/\frac{GDP_0}{POP_0}\right), \quad (5)$$

$$\Delta C_{enint} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln\left(\frac{TPES_t}{GDP_t}\Big/\frac{TPES_0}{GDP_0}\right), \quad (6)$$

$$\Delta C_{renew} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln\left(\frac{FE_t}{TPES_t}\Big/\frac{FE_0}{TPES_0}\right), \quad (7)$$

$$\Delta C_{FF} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln\left(\frac{FE_{it}}{FE_t}\Big/\frac{FE_{i0}}{FE_0}\right), \quad (8)$$

$$\Delta C_{emc} = \sum_{i=1}^{3} \frac{CO_{2it} - CO_{2i0}}{\ln(CO_{2it}) - \ln(CO_{2i0})} \ln\left(\frac{CO2_{it}}{FE_{it}}\Big/\frac{CO2_{i0}}{FE_{i0}}\right), \quad (9)$$

where CO_2 is the total carbon emissions, the summation of which is carried out for three types of fuel (oil, coal and natural gas); POP is the population; TPES is the supply of primary energy of all types; FE is the supply of all types of fossil fuels; FE_i is the supply of the i-th fossil fuel; CO_{2i} - emission of carbon dioxide from combustion of the i-th fuel.

4 Results

The recovery of the Russian economy after the economic crises of the 1990s and the growth in the utilization of production capacities led to an increase in greenhouse gas emissions. However, the advancing development of the service sector and the change in the structure of the Russian economy in favor of less energy-intensive industries in the 2010s led to the stabilization of carbon dioxide emissions [6,7] (Figure 1).
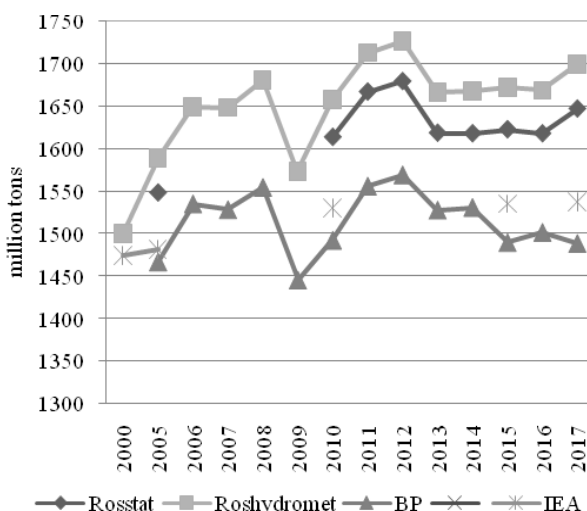

Fig. 1. Dynamics of CO2 emissions in Russia.

The analysis showed that the dynamics of CO_2 emissions in Russia is determined mainly by the growth rates of the population's well-being and the growth of industrial production. At the same time, in the period 2000-2012, the effect of welfare growth was partially offset by a decrease in the energy intensity of the economy, and in subsequent periods the potential for reducing energy intensity due to changes in the structure of the economy was exhausted. The contribution of the factor "growth of the welfare of society" to the increase in CO_2 emissions for the period 2000-2015 is estimated at 931.9 million tons. The contribution of the reduction in energy intensity to the dynamics of CO_2 emissions over the same period is estimated at -784.8 million tons.

The zero dynamics of CO_2 emissions in 2013-2017 is associated with a slowdown in economic growth. So the welfare (GDP per capita) of the population in 2017 decreased by 0.8% compared to the 2012 level. In the period 2015-2017, the contribution of this factor to the change in the volume of emissions amounted to 14.8 million tons. The stabilization, and in some years the growth of the energy intensity of the economy also provided a positive contribution to the dynamics of CO_2 emissions. Over the same period, the contribution of this factor is estimated at 21.3 million tons.

At the same time, the contribution of the technological factor is insufficient. So for the period 2000-2017, the improvement of technologies in the field of heat and electric energy production from fossil energy sources made it possible to reduce CO2 emissions by only 33 million tons. Another important constraint to the transition to a low-carbon trajectory of development is the low rate of implementation of energy-saving technologies in the production of energy-intensive industrial products, servicing residential and public buildings, which is reflected in the growth of energy intensity in recent years. In the production and distribution of electricity, gas, and water, the volume of pollutant emissions per ruble of value-added in 2017 increased by 2.8%, in manufacturing the value of the indicator remained at the level of the previous year. Thus, due to the exhaustion of the potential for reducing energy intensity due to structural changes in the economy, the energy intensity of GDP by 2018 increased by 2.6% compared to the 2015 level (Figure 2).
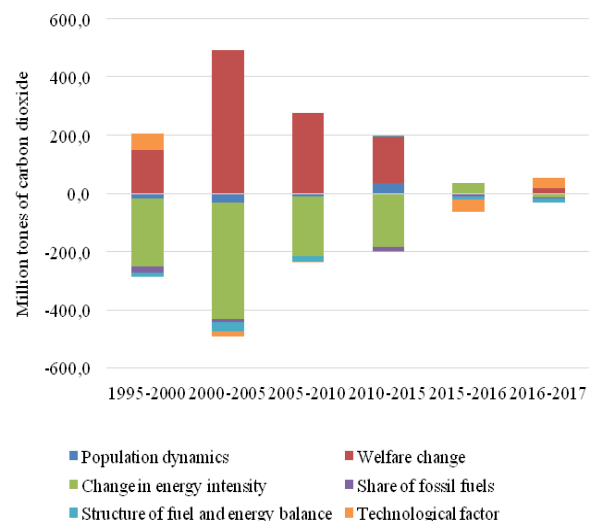

Fig. 2. Contribution of factors to changes in CO_2 emissions from fossil fuel combustion in Russia.

5 Discussion

Within the framework of the study, it is of particular interest to compare the ongoing changes in anthropogenic emissions of carbon dioxide in Russia and other countries of the world.

Calculations made based on this methodological approach for OECD countries showed a change in the structure of carbon dioxide emissions similar to Russia in the period 1990-2010. The main difference during this period was the impact of population dynamics on CO_2 emissions. For example, if a population decline was recorded in Russia, then the OECD population increased, which had a positive effect on CO_2 emissions [8-11] (Figure 3).
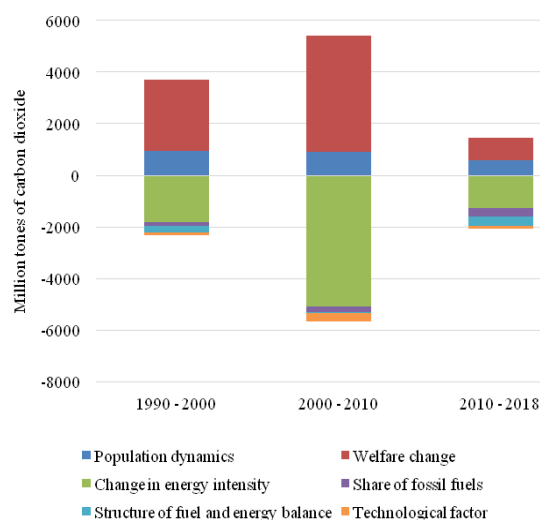

Fig. 3. Contribution of Factors to CO_2 Emissions from Fossil Fuel Combustion in OECD Countries.

However, in the last decade, Russia and the OECD countries are characterized by a significant difference in the structure of the increase in CO_2 emissions:

- Influence of energy intensity. In the previous decades, the decrease in the energy intensity of the Russian economy was mainly due to changes in the structure of the economy, but this potential has been practically exhausted. As a result, after 2015, this factor practically ceased to influence the dynamics of CO_2 emissions. In OECD countries, this factor continues to be a key factor in the process of reducing CO_2 emissions. In addition to structural changes, the introduction of modern energy-saving technologies contributes to a decrease in the energy intensity of the economy in the OECD countries;
- The growing influence of alternative energy in OECD countries on the reduction of CO_2 emissions. In Russia, alternative energy is developing at a slower pace than in the largest OECD countries and has a smaller impact on the dynamics of CO_2;
- Technological factor. During the past three decades, OECD countries have seen a steady decline in specific CO_2 emissions from burning

a kilogram of fossil fuels. However, in Russia, the dynamics of specific emissions are unstable. At the same time, the volume of emissions from burning a kilogram of coal makes a negative contribution to this indicator, while specific emissions from burning gas and oil tend to decrease.

6 Conclusion

Over the past ten years, the annual volume of greenhouse gas emissions in Russia has remained at a relatively stable level. Taking into account the low rates of economic growth (since 2013, the average annual growth rate of Russia's GDP has decreased to 0.7%), this may indicate insufficient measures to reduce the energy intensity of the economy and reduce greenhouse gas emissions.

The analysis showed that the possibilities of reducing harmful effects on the environment due to factors such as changes in the structure of the economy have been mostly exhausted. To achieve the greenhouse gas emission indicators presented in the Strategy for the Long-Term Development of Russia with a Low Level of Greenhouse Gas Emissions until 2050, it is necessary to intensify the development of alternative energy, the introduction of digital and energy-saving technologies in industries, and the introduction of technologies for the capture, storage and processing of carbon dioxide.

References

1. L.V. Eder, Forecast of world energy consumption: methodological approaches, comparative evaluation. Mineral resources of Russia. *Economics and management* **6** (2013)

2. E. Y. Khrustalev, P. D. Ratner. Advances in technology and energy efficiency in industry and transport. *The economic analysis: theory and practice* **2** (2015)

3. L. Eder, I. Filimonova, V. Nemov, A. Komarova, K. Sablin. Ecological aspects of economical development: Issues of forecast greenhouse gas emissions in road transport in Europe and regions of Russia. *E3S Web of Conferences. International Conference on Renewable Energy and Environment Engineering* **80** (2019)

4. New energy forecasts. *Energy Bulletin* **66** URL: http://ac.gov.ru/files/publication/a/19857.pdf (2018)

5. Ecology and economics: growing air pollution in the country. *Bulletin on current trends in the Russian economy* **39**. URL: http://ac.gov.ru/files/publication/a/17409.pdf (2018)

6. Key indicators of environmental protection. Statistical Bulletin. URL:

http://www.gks.ru/bgd/regl/b_oxr17/Main.htm (2019)

7. CO_2 emissions from fuel combustion. IEA 2019. URL: https://webstore.iea.org/co2-emissions-from-fuel-combustion-2019-highlights (2019)

8. A. E. Kontorovich, L. V. Eder, I. V. Filimonova. Paradigm oil and gas complex of Russia at the present stage. *In IOP Conference Series: Earth and Environmental Science* (2017)

9. L. V. Eder, I. V. Provornaya, I. V. Filimonova, V. D. Kozhevin, A. V. Komarova. World energy market in the conditions of low oil prices, the role of renewable energy sources. *Energy Procedia* **153** (2018)

10. I. V. Filimonova, L. V. Eder, M. V. Mishenin, T. M. Mamakhatov. Current state and problems of integrated development of mineral resources base in Russia. *In IOP Conference Series: Earth and Environmental Science* **84(1)** (2017)

11. I. V. Filimonova, I. V. Provornaya, S. I. Shumilova, E. A. Zemnukhova. Cluster analysis of Russian oil companies based on tax burden parameters. *Journal of Tax Reform* **5(1)** (2019)