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Trends in Russia's GDP Growth under Environmental Constraints

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ABSTRACT

The paper illustrates an approach to GDP growth in the context of an ecological economy. The **subject** of the research is the establishment of the interdependence of the state of the ecology of the environment and the results of human activity. The **aim** of the study is to determine the presence or absence of a relationship between pollutants in each type of environmental pollutants and the level of economic development of the country, represented by GDP per capita indicators. The **relevance** of the study is due to the ecologically unbalanced growth of GDP, which is accompanied by an increase in disproportions between the volume of pollutants emitted by the extractive, processing, processing, agricultural and infrastructure sectors of the economy, and the conditions of human life due to the deterioration of the "ecological quality" of the environment, which limits the possibilities for further development of human capital. The scientific **novelty** of the research lies in the development of economic and mathematical models, methods, and numerical algorithms for assessing and analyzing the state of air, water, and environmental pollution under the influence of the country's economic growth. **Methods** used: empirical and statistical analysis, building regression models, algorithmic and predictions, building time trends, etc. The authors based the methodology of substantiating the method for assessing the environmental constraints on GDP growth on an empirical study of the state of the environment and the state of the Russian economy in 2000–2018. **Results:** the authors have determined a set of indicators reflecting the state and trends of changes in environmental pollutants in Russia (carbon dioxide emissions, wastewater, production, and consumption waste) and their interdependence with economic development, which predetermine long-term social, environmental, and energy consequences. An algorithm has been developed to substantiate environmental restrictions on Russia's GDP growth in the period 2000–2018. The algorithm is based on a modified Kaya equation, through which the relationship between each type of pollutant and indicators of GDP per capita, energy resources, and industrial production is checked. In accordance with GDP growth, the forecast of environmental restrictions was developed according to scenarios of 10–40% and showed the inevitability of implementing a plan to prevent environmental pollution in Russia. It is **concluded** that Russia must promote environmental and low-carbon policies, reduce emissions, waste, and energy consumption over the next few decades to achieve sustainable development. The country is faced with the task of moving away from a nature-destroying economy, thereby saving natural capital, minimizing the costs of eliminating the negative environmental consequences of technogenic economic development in the future.

Keywords: ecological economics; Russia; GDP growth; sustainability; environmental constraints; wastewater; production and consumption waste; CO_2 emissions; Kaya's equation

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INTRODUCTION

GDP growth rates are the primary indicator of economic progress worldwide [1–4]. However, nowadays, the "benefit" for the economy has become inextricably linked with the "harm" to the environment.[1] It reinforces the illusion that the economy and the environment are separate and leads to the fact that politicians ignore environmental problems or contribute to their destruction for the sake of economic growth, even though there have been some justifications for a close interaction of economic and environmental factors [1]. Almost all modern researchers agree on one thing: economic growth is impossible without taking into account the impact on the environment. These and related issues have become the subject of ecological economics. R. Costanza has developed the meta-paradigm of ecological economics where he has concluded that a sustainable, desirable future is more critical than unsustainable GDP growth [5]. People need to recognize the limitedness of GDP growth by the quality of the environment that is promoted by the followers of the ecological economics direction [5–7]. The concept of ecological economics considers a person not as a consumer of natural resources, but as an essential component of an integral ecological-economic system, responsible for understanding his role in the overall global network of the biosphere, in preserving and managing it to achieve sustainability [8, 9]. In Russian practice, since the mid-80s of the 20th century, the introduction of the environmental restrictions on economic growth was actively discussed [10, 11]. E.A. Zhalsaraeva et al. (2019) have argued that environmental restrictions arise under the influence of human will and the stage of the region's socio-economic development. The authors have concluded, that environmental restrictions should be agreed upon at the level of states, region, and municipality levels, but in Russian's regions, it is not such an optimistic situation with such things [12]. The mechanism for managing the potential ecological production reserves should be developed with limitations according to the green passport system as a system of maximum permissible concentration (MPC) of pollutants.[2] Nowadays there is a need to find a balance between the interests of the Russian economy and the reduction of pollution. These things should be balanced with ecologically-oriented economic growth in terms of GDP[3] [14].

The authors' logic for investigating the environmental constraints to Russia's GDP growth is the following: (1) To understand the state of the problem: trends in environmental restrictions and targets; (2) To analyze the impact of environmental restrictions on targets, to ensure whether there is a close relationship between them; (3) To develop an algorithm for predicting the impacts of environmental restrictions on the Russian economic growth until 2030.

In this study, we have analyzed the Russian GDP growth for the period of 2000–2018 and have made a forecast until 2030. The authors agree that all types of pollutants resulted in production and consumption play an incredible role in the sustainable ecologically oriented economy. The authors refer to the volume of industrial production and the volume of consumed natural energy resources as targets since the level achieved by them predetermines the improvement of the ecological situation.

The research includes three blocks. The first block concerns the awareness of "environmental constraints". The variety of environmental restrictions is not universal for all states and even for all regions of one country. It is associated with natural geophysical features, natural resource availability, the level of development and specialization of the economy, and other objectively determined features. Therefore, the list of pollutants was substantiated and determined carefully. In the second block, the authors investigate the presence or absence of a relationship between pollutants, GDPPC, industrial production, and energy consumption. The authors calculated regression models, evaluating the measure and nature of their interdependence. The third block of research

[1] OECD. The Economy of Well-being: Creating Opportunities for People's Well-being and Economic Growth, Organization for Economic Co-operation and Working paper. 2019;33(102):1–54.

[2] Global Footprint Network Standards Committee, Ecological Footprint Standards 2009, Executive Editor Kitzes J. URL: https://www.footprintnetwork.org/content/images/uploads/Ecological_Footprint_Standards_2009.pdf (accessed on 26.08.2021).

[3] Decree of the President of the Russian Federation of 19.04.2017 No. 176 "On the Strategy of Environmental Safety of the Russian Federation for the Period until 2025", 2017 (In Russ.). URL: http://www.kremlin.ru/acts/bank/41879 (accessed on 26.08.2021).

assessment is environmental pollution under the influence of GDP growth. The authors have modified the Kaya identity formula, where emissions of pollutants are determined by the restriction into the atmosphere, polluted wastewater, industrial solid waste, and energy consumption.

The scientific novelty of the research lies in the development of economic and mathematical models, methods, and numerical algorithms for assessing and analyzing the state of air, water, and environmental pollution under the influence of the country's economic growth. Following Robert Costanza and his ideas, the authors have recognized that GDP growth, in the long run, could be decoupled with natural resource consumption.

The authors begin the paper with an overview of Russia's annual economic losses caused by the deterioration of the environment and related economic factors. The second part represents the sample data and methodology. The third part is the presentation of the obtained results of Russia's sustainability modeling.

METHODOLOGY

Data

The authors have developed a methodology of justification for the environmental constraints on Russian GDP growth between 2000–2018. The indicators have included emissions of pollutants, wastewater, production, and consumption wastes. The Russian economy has been represented by GDP, population, energy consumption, and industrial production indicators. The authors have used data from the Russian Statistical Yearbook, 2019 from the Federal State Statistics Service (Rosstat)[4] [15], where actual data concerning emissions of sulfur dioxide (SO_2), nitrogen dioxide (NO), carbon dioxide (CO_2), volatile organic compounds (VOC), ammonia emissions (NH_3) (thousand tons), volumes of waste generated production and consumption (million tons), volumes of contaminated wastewater (billion cubic metres), GDP (million rubles), and population indicators could be found. Industrial Production Index (IPI) and already spent natural energy resources expressed in million tons could be found on the Rosstat website — www.gks.ru. The full list of the research data can be found in Appendix A.

Methodological base

One of the most popular ways to assess the environmental constraints of GDP growth has been discussed in Kaya's paper. He has proposed a model of the GDP identity with key determinants, with relative values as crucial factors. Kaya identity is an identity that indicates that the total level of carbon dioxide emissions can be expressed as a product of four factors: population, GDPPC, energy intensity (per unit of GDP), and carbon intensity,[5] i.e. carbon energy footprint[6] [16, 17] (see Eq. 1–5).

$$F = P \times \frac{GDP}{P} \times \frac{E}{GDP} \times \frac{F}{E}, \quad (1)$$

where, F — CO_2 emissions from human-made sources; P — Population; GDP — Gross Domestic Product; E — Energy consumed. For the research purpose, the authors modified Kaya formula following way:

$$Y = P \times \frac{X}{GDP} \times \frac{Y}{X} \times \frac{GDP}{P}, \quad (2)$$

where Y is the factor that we want to test as a limitation (waste, emissions, resource consumption…), X is some factor with properties: (1) we can identify either trend or targets for the indicator $\frac{Y}{X}$; (2) we can identify either trend or targets for the indicator $\frac{X}{GDP}$. For example, for a CO_2 limiting indicator, X is the energy resource (E)

[4] Decree of the President of the Russian Federation dated 01.12.2016 No. 642 "On the Strategy of Scientific and Technological Development of the Russian Federation", 2016. URL: http://kremlin.ru/acts/bank/41449 (accessed on 26.08.2021).

[5] Energy Strategy of the Russian Federation till 2035 (in Russ.), 2017. URL: https://minenergo.gov.ru/node/18038 (accessed on 26.08.2021).

[6] State annual report "About ecological protection in Russian Federation" (in Russ.). 2018. URL: https://www.mnr.gov.ru/docs/o_sostoyanii_i_ob_okhrane_okruzhayushchey_sredy_rossiyskoy_federatsii/gosudarstvennyy_doklad_o_sostoyanii_i_ob_okhrane_okruzhayushchey_sredy_rossiyskoy_federatsii_v_2018_/ (accessed on 26.08.2021).

consumed. Since P, $\frac{Y}{X}$, $\frac{X}{GDP}$ are predictable, we can present the formula for Y as:

$$Y_f = \left(P \times \frac{X}{GDP} \times \frac{Y}{X} \right)_f \times \left(\frac{GDP}{P} \right)_f, \quad (3)$$

where Y is a factor that we want to check as a constraint (waste, emissions, consumed resources ...), X is some factor with the following properties: (1) we can determine either trends or target values for the $\frac{Y}{X}$ indicator; (2) we can determine either trends or target values for the indicator $\frac{X}{GDP}$. Thus, for the limiting indicator CO_2, the indicator X is the consumed energy resources (E). Indicator P, $\frac{Y}{X}$, $\frac{X}{GDP}$ could be forecasted, thus, the formula for Y could be written in the following form:

$$Y_f = \left(P \cdot \frac{X}{GDP} \cdot \frac{Y}{X} \right)_f \cdot \left(\frac{GDP}{P} \right)_f \quad (4)$$

or:

$$Y_f = \left(P \cdot \frac{X}{GDP} \cdot \frac{Y}{X} \right)_f \cdot \left(\frac{GDP}{P} \right)_b \cdot \left(1 + K_f \right), \quad (5)$$

where Y_f is a forecasting factor that we want to test as a limitation (waste, emissions, resource consumption...), $\left(P \cdot \frac{X}{GDP} \cdot \frac{Y}{X} \right)_f$ is some factor with properties, b — base year (in our case-2018), K_f — relative change in the indicator $\frac{GDP}{P}$ in the forecast year in comparing with the base year 2018. Eq. 5 helps to find the maximum possible value of GDP growth under given constraints. We can assume that Kf equals 10% and 20% and this would directly affect the value of Y. This approach makes it possible to predict the value of the limiting indicator at different growth rates $\frac{GDP}{P}$. Thus, we set the limit values for the limiting indicator and determine the growth limits of the indicator $\frac{GDP}{P}$. The model allowed us to develop an algorithm for assessing Russia's GDP growth under the environmental constraints, presented in *Fig. 1*. Y has a maximum permissible value [Y]. Accordingly, a Kf needs to be found so that Y is equal to [Y]. This is the maximum possible Kf (max).

RESULTS

Environmental constraint analysis results

During the study period, the state of the environment was unstable. Emissions of air pollutants from 2000 to 2018 show that the maximum level of emissions took place from 2004 to 2007, significantly decreased in 2014 with a slight increase in 2018. The total volume of emissions of air pollutants in 2018 amounted to 32.3 million tons: 17.1 million tons were emitted by stationary sources and 15.3 million tons by mobile sources (vehicles) [18]. Such dynamics were developed under the influence of a sharp increase in emissions of Carbon Dioxide (CO_2) from stationary and mobile sources in 2003–2007. CO_2 accounts for more than half of the total volume of gas emissions into the atmosphere. Therefore, assessing the environmental restrictions on Russia's GDP growth deserves special attention. The specific gravity of all other air pollutants in the total volume of emissions is in the range of 1 to 11%. In the same way, there was an increase in the amount of waste production and consumption by 4.5 times (from 1603 thousand tons up to 7,266.1 billion tons).

According to Russian State Statistics, the volume of wastes annually increases by more than five billion tons. This is twice as many as in all EU countries in terms of comparable accounting. The waste dynamics are provoked by the growth of industrial production and retail turnover; weak development of the waste

management and recycling industry, and non-effective legal regulation of waste disposal[7] [19].

In recent years, Russia has seen relatively stable CO_2 emissions. The energy sector accounts for the majority of greenhouse gas emissions. For example, 78.9% in 2017. Simultaneously, in Russia, the land-use change and forestry sector is a significant net sink of greenhouse gases, offsetting about 26.8% of emissions occurring in other industries. The volume of discharge of contaminated wastewater decreased significantly during the study period from 55.6 billion cubic metres to 40.1, i.e. 28% as a result of reduced pollutant emissions of all species except nitrates. The effect is also amplified by the fact that GDP grew by 76% during this period, and the withdrawal of freshwater decreased by 19%. Electricity and heat were the primary sources of discharge of contaminated wastewater[8] [20]. Emissions of nitrates doubled from 2000 to 2013. The growth was caused by a change in economic structure in terms of reducing high-tech production and increasing the growth of production, the waste of which are nitrates: components of rocket fuel, production of explosives, pyrotechnics, drug production, and glass production.

The analysis of the state of the Russian economy's environment made it possible to understand trends in pollutants (emissions), in which energy resources were used during the study period and achieved useful indicators: GDP, industrial production, volumes of natural energy resources (spent), expressed in million tones of conventional fuel and how to consider them. The decline in the population of 2005–2012 was due to the economic crisis and institutional economic regulation problems. The social support since 2012 and some stabilization of financial mechanisms have contributed to population growth as well [14, 15]. Despite the fluctuations in population, GDPPC in Russia is characterized by a positive trend. The results of the economic processes that have a substantial impact on the environment were represented by the volume of industrial production and the number of energy resources spent is presented in *Fig. 2, 3*. Both graphs show a persistently positive growth trend beyond the exclusion of some recession during the 2008–2009 crisis.

However, in terms of environmental constraints on the development of the economy, these results cannot be considered positive, as emissions into the atmosphere, wastewater pollution, and solid waste of production and consumption have increased. For determining the values of environmental constraints on GDP growth, we need to understand the quality of the relationships, the nature of the impact between pollutants and GDP, and the results of economic processes that have an intense effect on pollution. Based on the concept of an environmental economy, we analyze the existence or absence of a relationship between pollutants and Russia's level of economic development represented by GDPPC, industrial production, and consumption of natural energy resources. We calculated regression patterns of GDPPC dependence and pollutants of each species (see *Fig. 2, 3, Tabl. 1, 2*).

Table 1 highlights the close relationship between GDPPC and Sulfur Dioxide (SO_2) and Ammonia (NH_3). Both of these substances are captured in the atmosphere and can be reused in production. Of the three remaining elements, only CO_2 has a significant impact. Two types of pollutants are closely related to the Russian Federation level of economic development: wastes from production and consumption and wastewater growing in proportion to GDP growth.

The authors observed a high correlation between CO_2 and GDPPC. It is not clear if this is a false correlation or a real relationship from 19 annual datasets. However, there are no more annual official data. Moreover, if we take a more extended period, then during it the conditions will change, in particular, the technology, which will make the dependence invalid, since the conditions at the beginning of the period will differ from the conditions at the end. However, the research task is urgent, the ability to trace the links between GDP and environmental impact is a prerequisite for a green economy. Sustainability cannot be ensured without this. So, the paper research technique helps to solve this problem. The solution is based on the Kaya formula. In fact, in the classical form, it allows to present CO_2 emissions as the product of four indicators, three of which (population, carbon

[7] Bulletin on current trends in the Russian economy. Ecology and economics: dynamics of air pollution in the country on the eve of the ratification of the Paris Agreement (in Russ.), 2019, p. 1–226. URL: https://ac.gov.ru/files/publication/a/23719.pdf (accessed on 26.08.2021).

[8] Federal State Statistics Service (Rosstat), Russian Statistical Yearbook, 2019. URL: https://gks.ru (accessed on 26.08.2021).

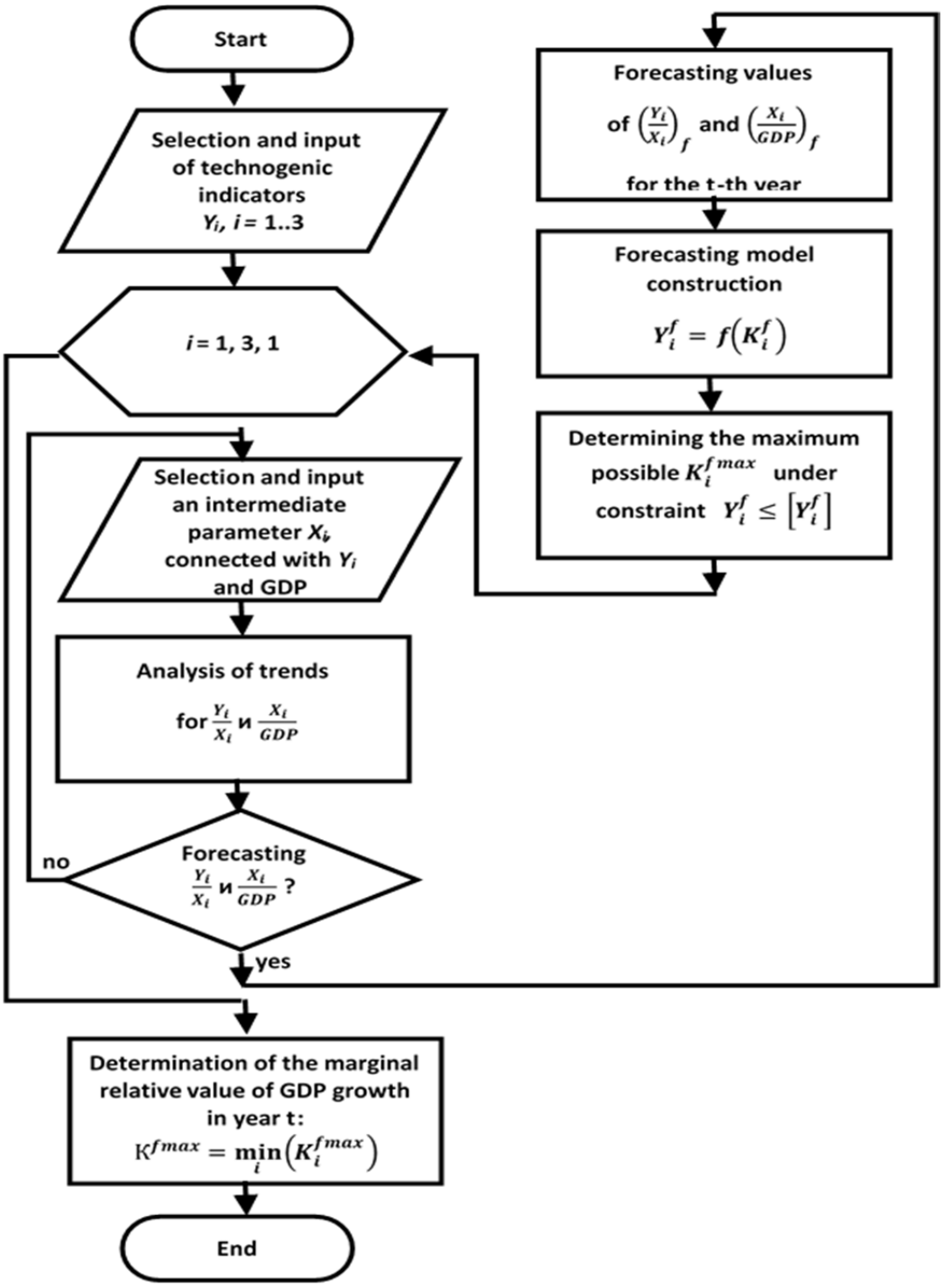

Fig. 1. **Assessment of Russia's GDP growth environmental limits**

Source: authors' methodology.

footprint (CO_2/Energy consumed) and energy intensity) are spelled out in the strategic documents of the country's development and, accordingly, limit values can be determined for them. The author does the same for other emissions by selecting an X indicator. The autoregressions presented in the work are needed for experts to simplify the task of determining values. It is also proposed to take into account not only the identified regressions but also the declared state goals, as, for example, we do it with garbage, when we reduce the predicted value of the indicator by 14%, as indicated in the National Project "Ecology".

Table 1 and *Fig. 2* show that not all substances polluting Russian airspace have a considerable effect

Table 1

Regression models of pollutants in emissions to the environment and their extent are related to the level of GDPPC

Waste	Abbr	Function	R^2
Sulphur dioxide	SO_2	$-2.18X + 5314$	0.92
Nitrogen dioxide	NO_2	$0.13X + 3460$	0.03
Carbon Dioxide	CO_2	$-1.91X + 17041$	0.19
Volatile Organic Compounds	VOC	$-0.29X + 2996$	0.05
Ammonia	NH_3	$0.095X + 35.99$	0.97
Waste from production and consumption	W	$6.84492X + 1725.75$	0.95
Wastewater discharge	WD	$0.02114X + 55.5165$	0.93

Source: authors' calculations.

on the level of economic development: nitrogen dioxide and volatile organic compounds do not have a significant impact. Besides, Sulfur Dioxide (SO_2) and Ammonia (NH_3) are easily caught and can be reused in production. This fact explains their high closeness to the indicator of the level of economic development. However, the proportion of substances in total emissions ranges from 1% to 50–53%. Carbon Dioxide accounts for more than 50% of the total emissions into the atmosphere. Therefore, in forecasting the value of GDPPC by 2030, under the influence of polluters, it is advisable to take into account trends in the development of CO_2 emissions. This statement is justified by the fact that the strategy of socio-economic development of Russia until 2030 does not provide a sharp change in the structure of the economic complex. Consequently, changes in pollutant emissions should be proportionate to changes in production volumes.

Although wastewater discharges have decreased from 2000 to 2018, we have analysed the behaviour of pollutants. *Table 2* shows the components that contaminate succulent waters and their relationship to GDP.

Table 2 shows that all kinds of pollutants in wastewater have a significant impact on Russia's economic development level. However, the measure of this influence is different but relatively high (*R* 2 over 0.5). However, *Fig. 3* shows that pollutants are reduced in wastewater. The only exceptions are nitrates. The elasticity of the effect of each wastewater pollutant on the level of economic development is not significant. Therefore, in predicting the trend of Russia's economic growth by 2030, under the influence of environmental pollutants, it is reasonable to take into account (use) the cumulative value of wastewater.

Comparative analysis of the impact on the level of economic development of pollutant types is presented in *Table 3*.

According to R 2 coefficients, the relationship between pollutant types and GDP is significant. The most considerable GDP changes coincide with a change in the mass of waste production and consumption (*R* 2 q0.95), with no less significant impact on the GDP of wastewater (*R* 2 q0.93).

The impact of gas emissions by stationary and mobile sources on GDP per capita is the smallest of all pollutant types (*R* 2. 0.45). Such a significant correlation between all types of pollutants and the state of GDP per capita updates the assessment of environmental constraints for GDP growth by 2030. Regression models of pollutants and the measure of their connection with the natural energy resources spent, expressed in millions of tons' conventional fuel can be seen in *Appendix A*. Full calculation results see in the *Tables 4–6, Fig. 4–6*.

Analysis results

The authors have verified the interrelationship between every type of pollutant and the next indicators:

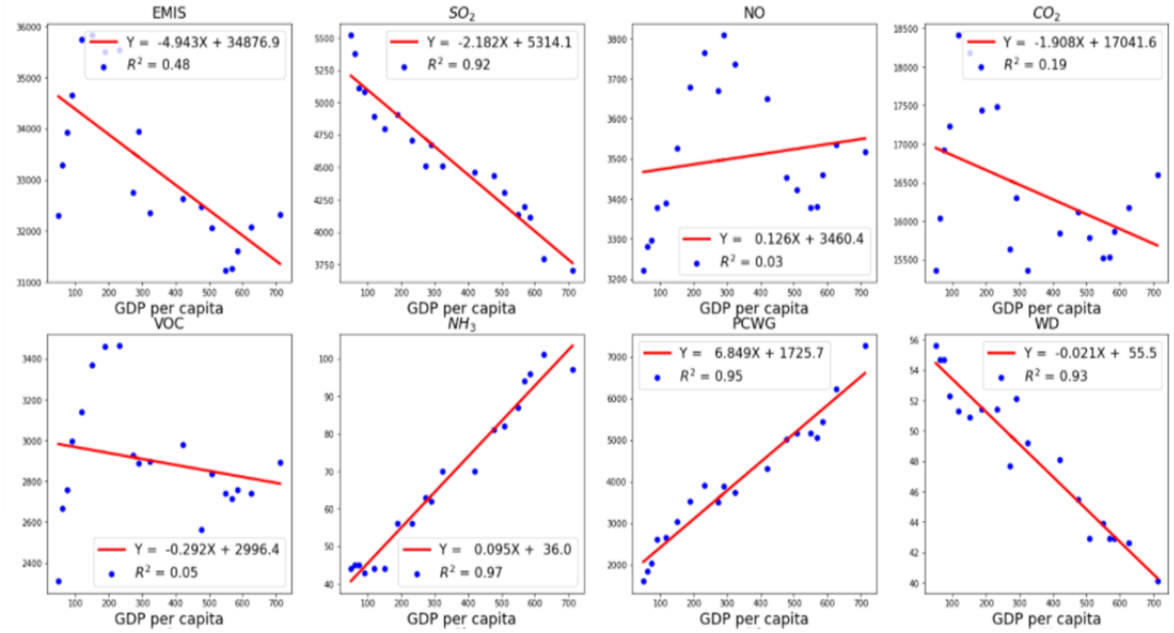

Fig. 2. **Dependencies between the number of pollutants and the level of Russia GDPPC**

Source: authors' calculations.

Table 2

Emissions of pollutants and their ratio to GDPPC regression models (thousand rubles)

Substances that pollute water drains	Abbr	Function	R^2
Sulphates	S	−0.0012*X* + 2.55	0.55
Chlorides	Ch	−0.0028*X* + 7.12	0.28
Nitrogen	Ni	−0.018*X* + 41.03	0.53
Nitrates	N	0.28*X* + 269	0.6
Fats, oils	FAO	−0.020*X* + 12.83	0.81
Phenol	Ph	−0.064*X* + 53.92	0.84
Plumbum	Pb	−0.035*X* + 24.86	0.76
Hydrargyrum	Hg	-0.0003*X* + 0.172	0.74

Source: authors' calculations.

GDPPC is the country's economic development level (GDP billion rubles divided by P-population (million people)

E/GDP is the energy intensity of the GDP unit (E — natural energy resources spent (mln.t.) divided by GDP (billion rubles)

F/E is a carbon energy footprint (F — CO_2 emissions from human-made sources (thousand tons) divided by consumed natural energy resources, expressed in millions of tons of fuel equivalent (million tons)

W/Y is an environmental pollution indicator (W — waste production and consumption per unit of industrial production (where W is the volume of waste production and consumption (billion tons) divided by Y — the volume of industrial production (billion rubles)

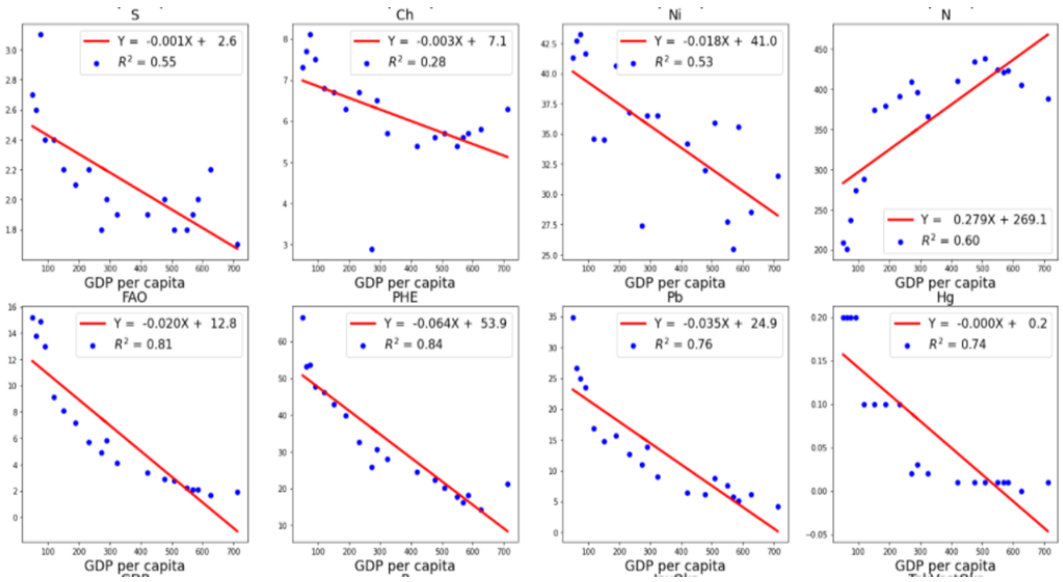

Fig. 3. **Dependence between pollutants in runoff and the development of the Russian economy (GDP per capita) (1–8)**

Source: authors' calculations.

Table 3

Impact of pollutants on the level of economic development

Types of pollutants	Abbr	Function	R^2	Quadrant upper fig
Emissions	EMIS	$-4.94X + 34877$	0.48	No. 1
Waste	W	$6.85X + 1726$	0.95	No. 7
Wastewater discharge	WD	$-0.0214X + 55.52$	0.93	No. 8

Source: authors' calculations.

IPI/GDP — Industrial Production Index per unit of GDP

F/IPI — F — CO_2 emissions from human-made sources (thousand tons) to Industrial Production Index (%)

W/IPI — Waste of production and consumption (billion tons) relative to the Industrial Production Index (%).

An analysis of the relationship between indicators reflecting the environmental constraints of Russia's GDPPC is presented in *Table 4* and *Fig. 4*.

Table 4 provides regression models of the indicators' interdependence reflecting the environmental constraints of GDPPC growth with a fairly high link: 0.56; 0.63; 0.87; 0.88.

The correlation between elements of the Kaya formula was analysed. In the carbon footprint of the population, 0.1 of the P. GDPPC dependence is 87% dependent on energy consumption E/GDP, and the energy consumption is explained by 87% energy intensity. At the same time, carbon energy footprint is 88% dependent on energy intensity.

Fig. 4 shows the trend of regression dependence. Thus, the following trends are characteristic of the Russian economy during the study period: with the growth of the population, the level of GDPPC is growing, while the energy capacity and carbon footprint are decreasing; As economic development increases, energy intensity and carbon footprint are reduced; Energy intensity is also increasing as the carbon footprint grows.

Thus, all the received dependencies are not logically inconsistent and statistically reliable, which gives us the right to use indicators reflecting the environmental limitations of Russia's GDPPC growth to calculate the GDPPC forecast by 2030.

Table 4

Relationship of the indicators reflecting the environmental limits of GDPPC Growth (for the GDPPC forecasting algorithm till 2030)

	P	GDPPC	E/GDP	F/E
P		79.62X – 1053.2	–0.0059X + 0.884	–0.139X + 28.796
		R^2 = 0.56	R^2 = 0.28	R^2 = 0.10
GDPPC	0.007X + 141.13		–0.0001X + 0.078	–0.003X + 10.16
	R^2 = 0.56		R^2= 0.87	R^2 = 0.63
E/GDP	47.85X + 145.9	8918.4X + 754.363	5689X + 7.567	36.25X + 7.455
	R^2 = 0.28	R^2 = 0.87	R^2 = 0.67	R^2 = 0.88
F/E	0.756X + 150.8	196.4X + 2151.7	0.024X – 0.17	0.013X – 0.15
	R^2 = 0.10	R^2 = 0.63	R^2 = 0.88	R^2 = 0.65

Source: authors' calculations.

To determine every species pollutants' ecological limits: emissions into the atmosphere; wastewater discharge; solid waste of economic activity and the population should be aware of their limits, which were achieved in the country's economy in 2018. For this purpose, the authors built various scenarios of every parameter that characterize indicators' conditions. The authors accepted the value of the parameter reached in 2018 as its limit and then used the formula (Eq. 3) to assess environmental constraints. Then, the authors accepted the assumption of the intensity of GDPPC growth by 10–20–30–40% until 2030.

In the study, we use the advantage of the Kaya model, which we have converted into a modified formula (*Eq. 5*). The result of the calculation is given in *Fig. 9*. It is clear from the figure that with the planned GDPPC growth from 0 to 40% while maintaining the existing feasibility study level, CO_2 emissions increase from the actual level of 2018 by 25% and reach 19,500 thousand. If GDPPC growth increases by 10%, CO_2 emissions would decrease by 296,000 tonnes. If CO_2 emissions increase by 25% by 2030, GDPPC will increase by 40% to RUB 1,000 billion; 30% — RUB 910 billion; at 20% — RUB 870 billion; 10% — RUB 800 billion.

Analysis of the CO_2 emissions into the atmosphere

For the prediction of the carbon dioxide value as a limiting environmental indicator of energy consumption by 2030, the authors extrapolated the energy intensity functions of the GDP until 2030 (*Fig. 7*) and the function of the carbon footprint (*Fig. 8*).

To predict the ecological limit for carbon dioxide emissions, the per capita energy intensity limit is taken as 0.017, as the best value achieved in 2018 (*Fig. 7*). The carbon footprint limit is shown in *Fig. 8*. The best carbon footprint was achieved in 2014 at 8 million cubic meters. m. carbon dioxide emissions per unit volume of consumed natural energy resources.

Wastewater discharge analyses

To predict the value of wastewater discharge as an environmental limiter of GDP growth by 2030, the authors extrapolated the functions of industrial production per unit of GDP until 2030 (*Fig. 10*) and the function of wastewater emissions / per unit of industrial production (*Fig. 11*).

To predict an environmental limit, "the amount of contaminated wastewater" is the limit of the industrial output per unit of GDP (expressed by the index) of 0.0015. *Fig. 11* shows that the limit for wastewater emissions per unit of industrial production has fluctuated from 0.30 to 0.2. Both figures show that the lowest value has achieved in

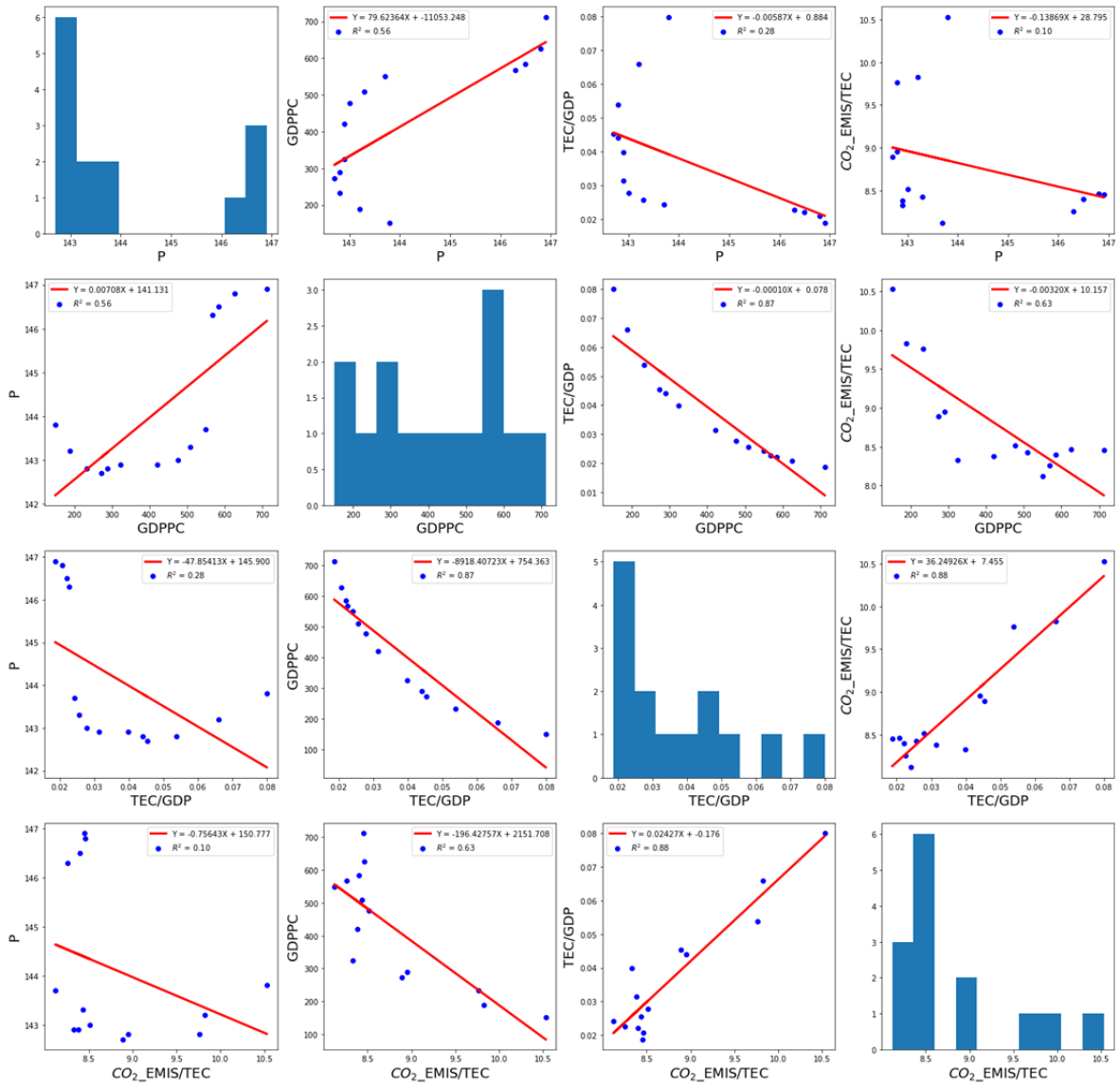

Fig. 4. **The nature of the relationship between environmental constraints (CO_2 and the number of natural energy resources spent) on Russia's GDPPC growth**

Source: authors' calculations.

Table 5

Models of the relationship of indicators reflecting environmental constraints (wastewater volume) and industrial output per GDPPC growth are required for the GDP forecasting algorithm by 2030

	P	GDPPC	IPI/ GDP	F/IPI
P		79.62X – 1053.2	–0.0004X + 0.066	–0.021X + 3,351
		R^2 = 0.56	R^2 = 0.28	R^2 = 0.53
GDPPC	0.007X + 141.13		–0.00001X + 0.006	–0.0003X + 0.423
	R^2 = 0.56		R^2 = 0.86	R^2 = 0.98
IPI/GDP	–638.4X + 146.04	–119633X + 781.6		32.03 + 0.213
	R^2 = 0.28	R^2 = 0.86		R^2 = 0.84
F/IPI	–25.3X + 151.95	–3636.3X + 1547.3	0.026X – 0.005	0.021X – 0.04
	R^2 = 0.53	R^2 = 0.98	R^2 = 0.84	R^2 = 0.75

Source: authors' calculations.

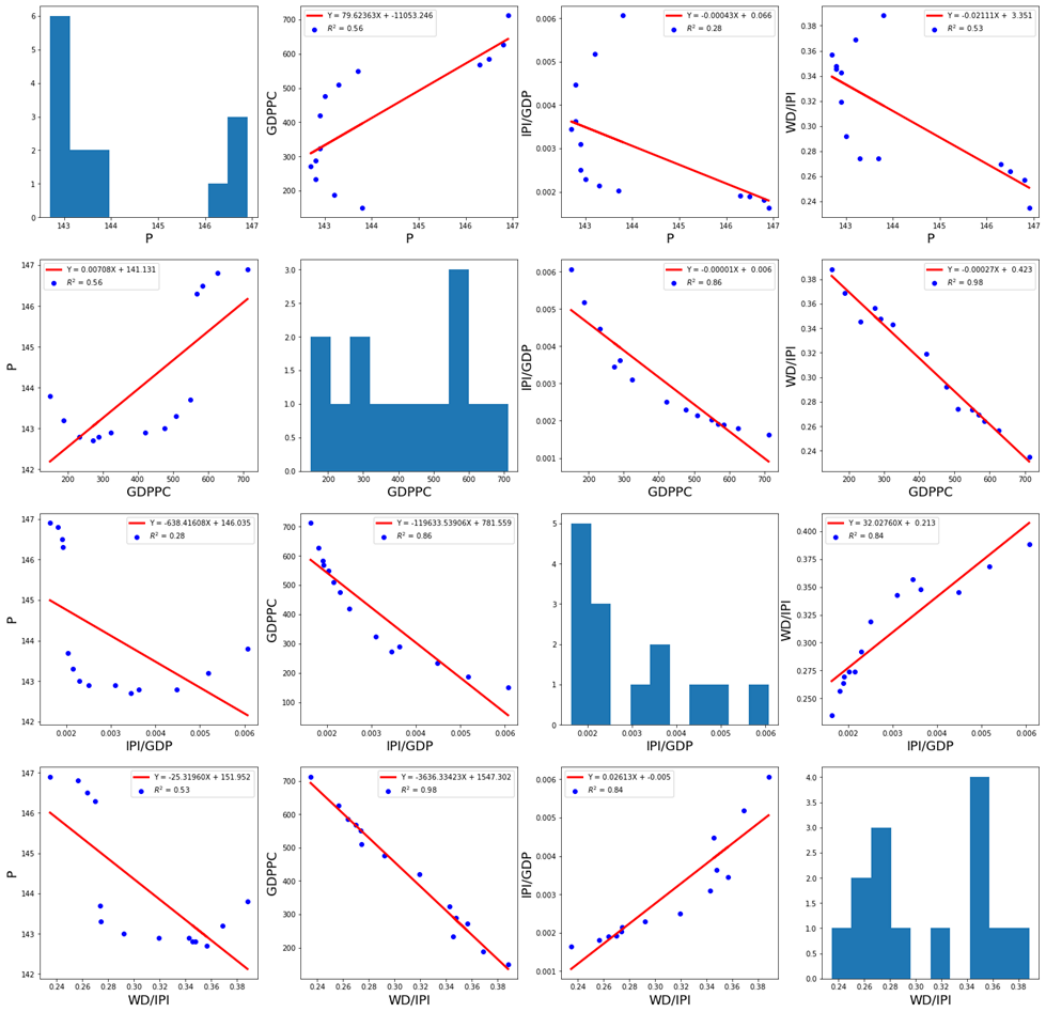

Fig. 5. **The nature of the relationship between environmental constraints (wastewater volume) and the size of industrial production and GDPPC growth required for the GDP forecasting algorithm by 2030**

Source: authors' calculations.

Table 6

Models of the relationship of indicators reflecting environmental constraints (the volume of waste production and consumption) and the volume of the industrial production per GDP growth required for the GDP forecasting algorithm by 2030

	P	GDPPC	IPI/GDP	W/IPI
P		79.62*X* – 1053.2	–0.0004*X* + 0.066	2.454X + –323.3
		R^2 = 0.56	R^2 = 0.28	R^2 = 0.59
GDPPC	0.007*X* + 141.13		–0.00001*X* + 0.006	0.029X + 18.22
	R^2 = 0.56		R^2 = 0.86	R^2 = 0.89
IPI/GDP	–638.4*X* + 146.04	–119633*X* + 781.6		–3155. 8*X* + 39.77
	R^2 = 0.28	R^2 = 0.86		R^2 = 0.66
W/IPI	0.239*X* + 136.9	31.289*X* – 525.7	–0.00021*X* + 0.009	23.289*X* – 435,8
	R^2 = 0.59	R^2 = 0.89	R^2 = 0.66	R^2 = 0.78

Source: authors' calculations.

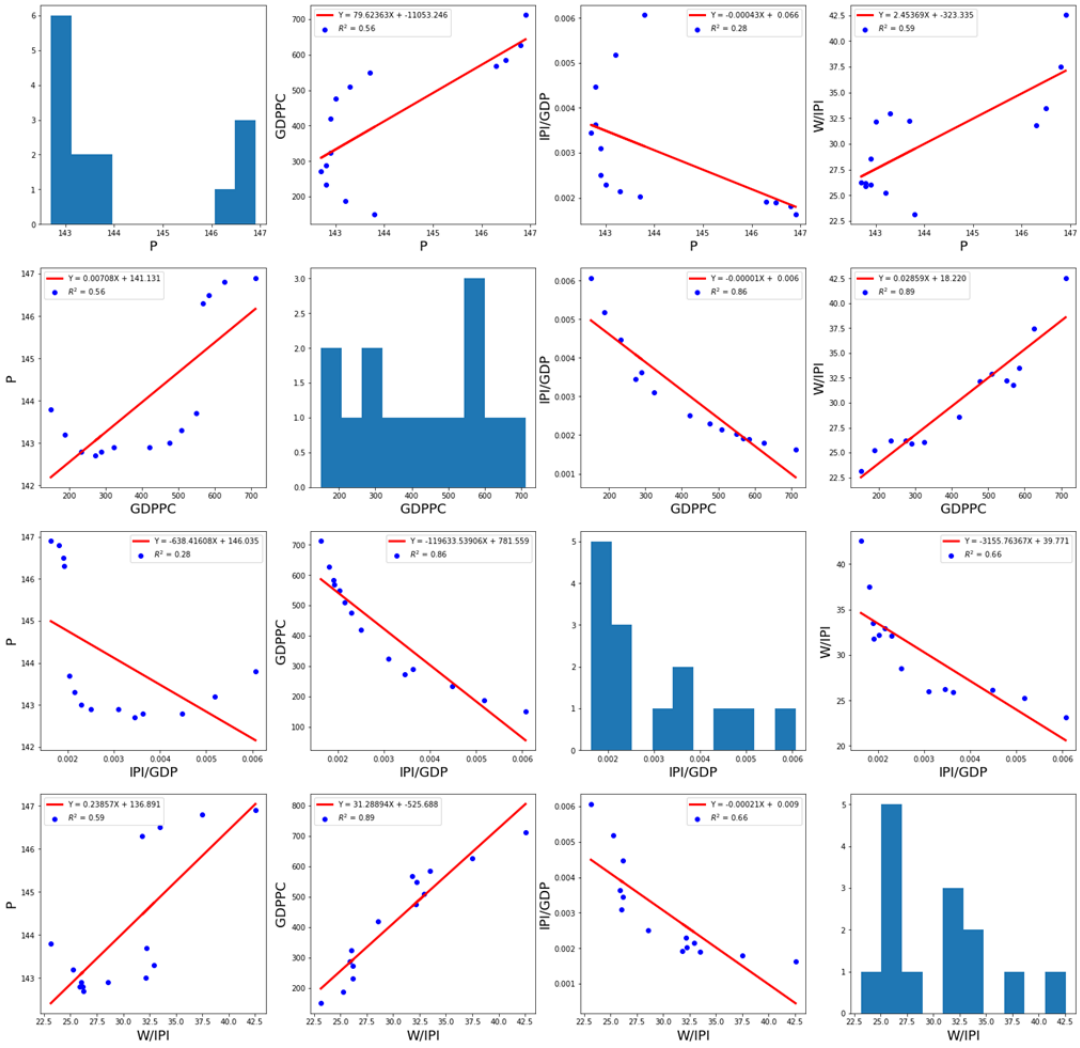

Fig. 6. **The nature of the relationship between environmental constraints (the volume of waste production and consumption and the volume of industrial production) on Russia's GDP growth**

Source: authors' calculations.

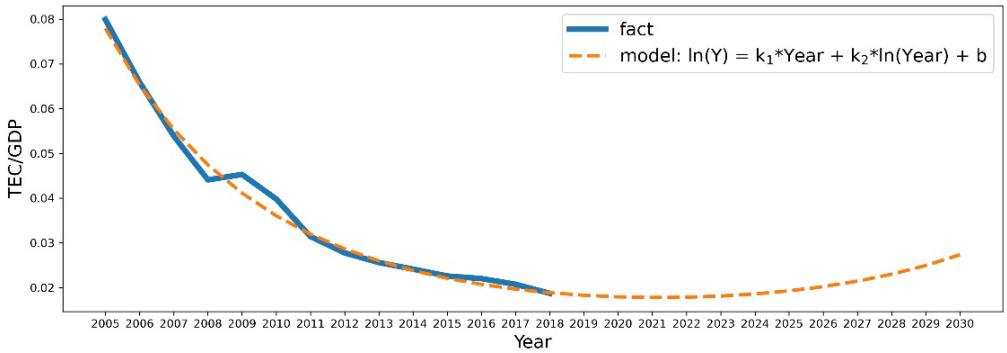

Fig. 7. **The trend of changing energy intensity of a unit of GDP until 2030 (the amount of natural energy resources spent is a million tons of conventional fuel divided by billion rubles of GDP)**

Source: authors' calculations.

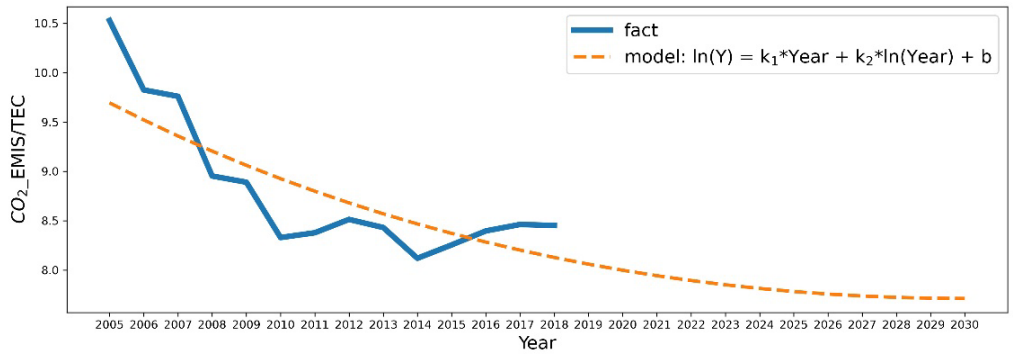

Fig. 8. **Carbon footprint trend to 2030**

Source: authors' calculations.

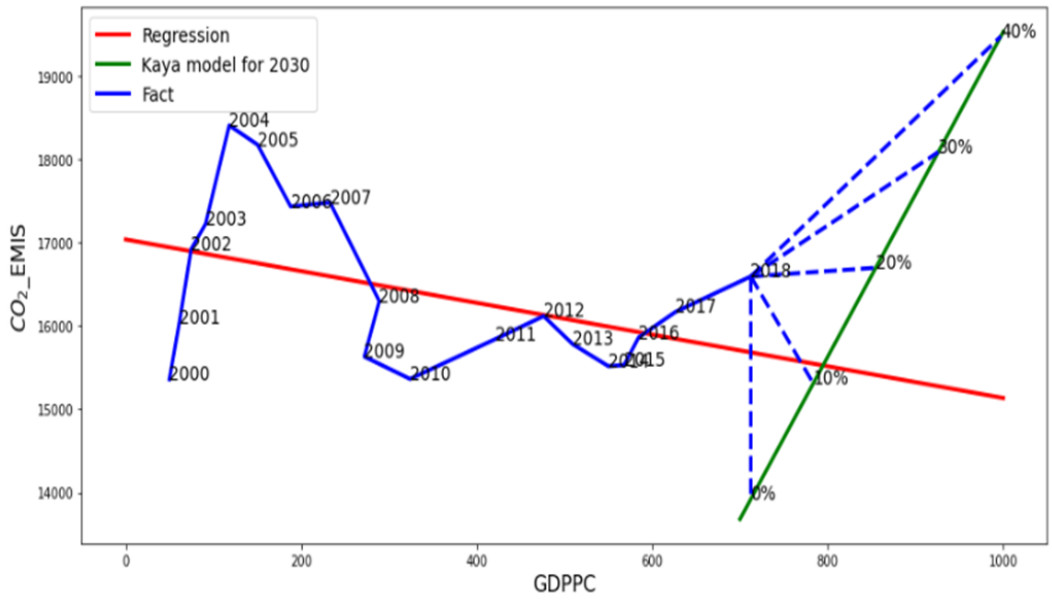

Fig. 9. **Dynamics of CO_2 emissions with 10–20–30–40% of Russia's GDPPC growth scenario by 2030**

Source: authors' calculations.

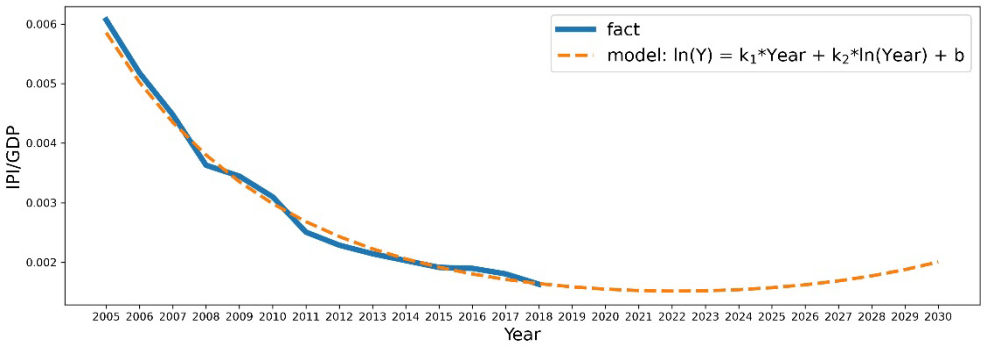

Fig. 10. **IPI/GDP trends until 2030**

Source: authors' calculations.

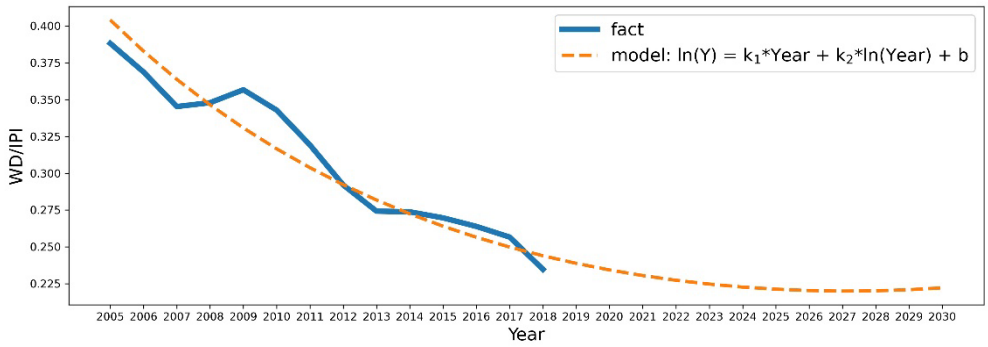

Fig. 11. **The trend of changes in wastewater emissions/per unit of industrial production until 2030**
Source: authors' calculations.

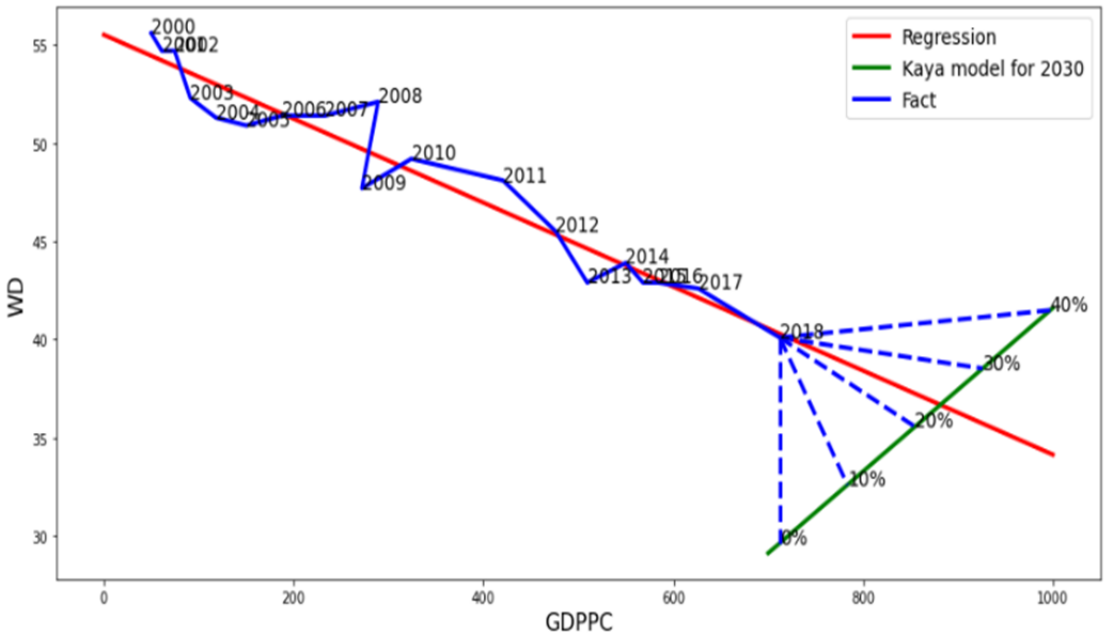

Fig. 12. **Emissions forecast in case of GDP growth per capita by 0, 10, 20, 30 and 40% concerning 2018**
Source: authors' calculations.

2018. It is clear from *Fig. 11* that with the planned GDPPC growth from 0 to 40%, the amount of contaminated wastewater would increase from the level of 2018 by 2% and reach 41 billion m^3 in 2030. With GDPPC growing by 30% by 2030 compared to 2018, emissions of contaminated wastewater would decrease by 3%.

Fig. 12 shows a reduction in GDPPC depending on wastewater discharge under the 10–40% scenario. Thus, with an increase in wastewater emissions by 40% in 2030, GDPPC would reach RUB 1000 thousand; 30% — RUB 910 thousand; 20% — RUB 870 thousand; 10% — RUB 800 thousand. At 20% — 870; at 30% — 910 and at 40% — RUB 1000 thousand.

To predict the value of solid waste in production and consumption, the authors extrapolated the functions of production pollution (the volume of waste production and consumption divided by industrial production) (see *Fig. 13*) and the volume of industrial production per unit of GDPPC until 2030 (*Fig. 14*).

The limit of industrial production per unit of GDPPC and pollution of production (waste of production and consumption per unit of industrial production) is 55 (maximum) and 0.0015, as the lowest level achieved in 2018.

Then, we can observe the wastes products forecast until 2030.

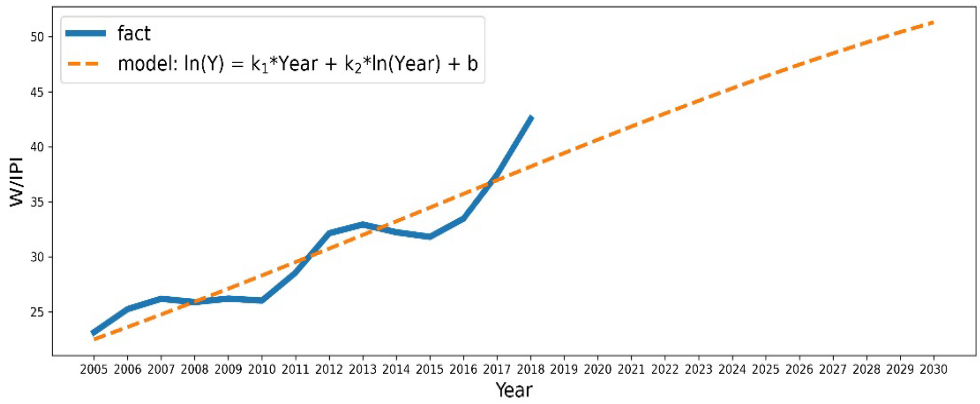

Fig. 13. **Waste production and consumption divided by industrial output, trend until 2030**

Source: authors' calculations.

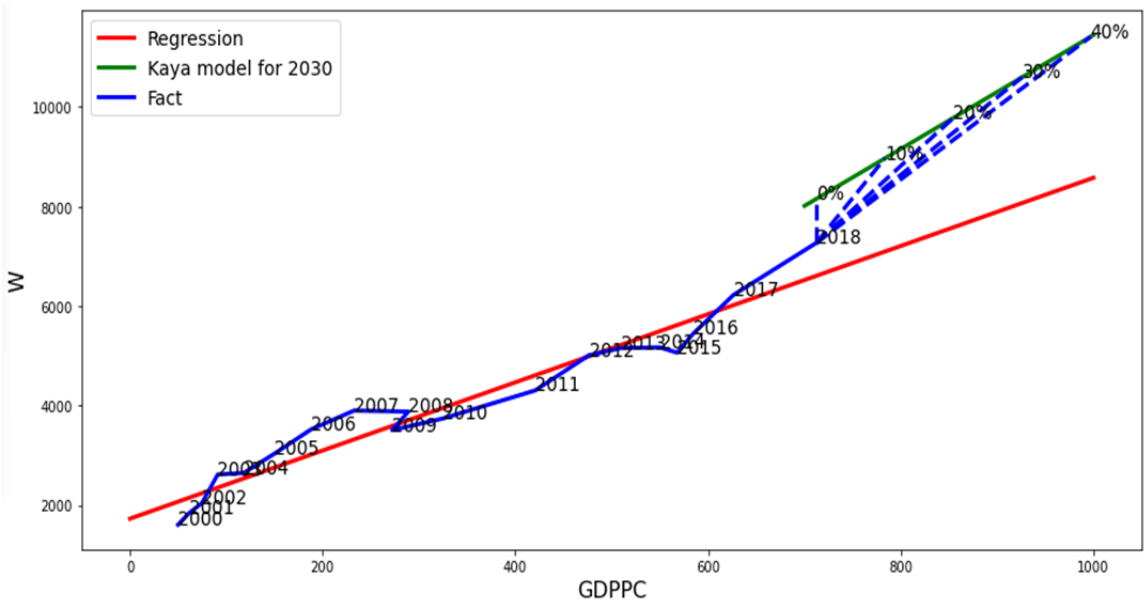

Fig. 14. **Dynamics of changes in waste production and consumption volumes, while GDP growth by 40% billion tons**

Source: authors' calculations.

Fig. 14 shows that if the current technological production level is maintained, the volume of waste production and consumption will grow faster than GDP pc. If national projects are implemented to increase the recycling rate from 60% to 86%, GDP growth options will change as presented in *Fig. 15*. The trend of GDP pc changes and changes in wastes would be almost parallel.

If the carbon footprint is maintained at the level of 2018, economic growth (GDP per capita) could be increased by another 10%. If the country needs to allow only 30 million cubic metres wastes per year, to curb the deterioration of the environment, Russia should be satisfied with GDPPC at the level of 2018.

DISCUSSION

Environmental sustainability should be an essential feature of the new sustainable economic growth model [16–18]. Congrong Yao et al (2015) emphasized that a better understanding of driving forces of every country's change in CO_2 emissions is to develop a broadly acceptable agenda for sustainable growth.[9] Ecologically unbalanced GDP growth is accompanied by an increase in disproportions between the volume of pollutants emitted by the extractive, processing,

[9] Bulletin on current trends in the Russian economy. Ecology and economics: dynamics of air pollution in the country on the eve of the ratification of the Paris Agreement (In Russ.), 2019, pp. 1–226. URL: https://ac.gov.ru/files/publication/a/23719.pdf.

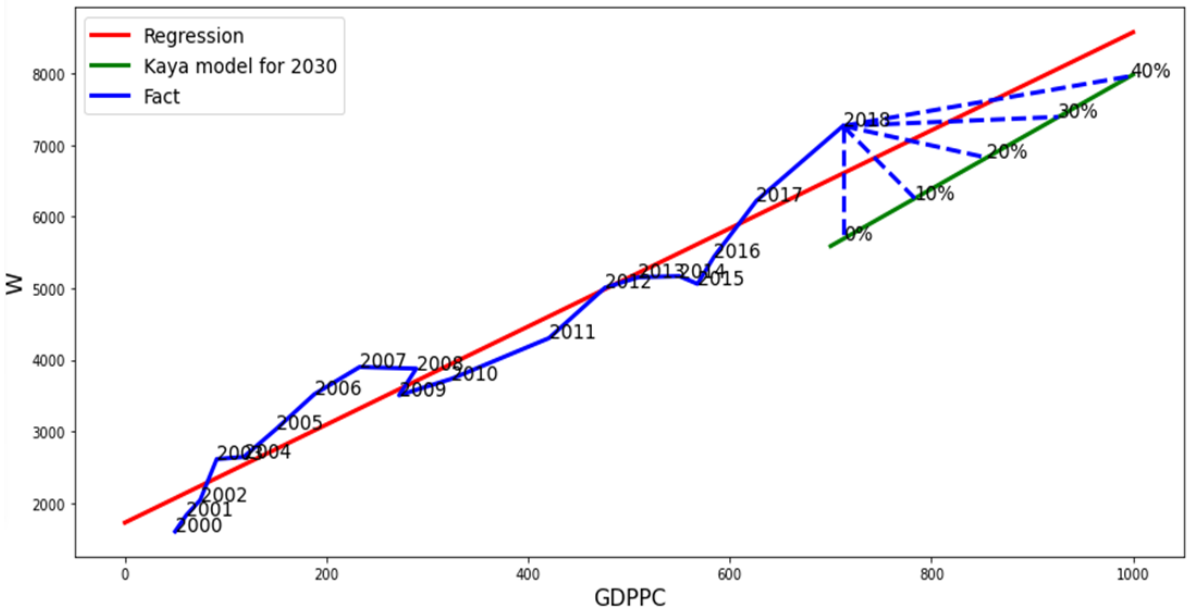

Fig. 15. **Dynamics of changes in waste production and consumption provided that national**

Source: authors' calculations.

agricultural and infrastructure sectors of the economy, and the conditions of human life. It is necessary to study the dynamics of changes in environmental restrictions and their impact on the quality of life [19]. The (IPCC) Intergovernmental Group of Experts on Climate Change (Mitigation of Consequences) also gave great attention to the methodology for studying the problems of the economic growth environmental constraints [20].

The governments of all countries are concerned about the quality of life. Moreover, usually, this estimate is justified by economic growth, expressed in GDP. However, economic growth is based on natural resources usage and wastes production. The most important thing is how are the two processes interconnected: the production of vital products and the production of pollution. Nowadays, is less attention paid to the production of pollutants, and as a result, the growing environmental threat. To comprehend and solve this problem, the authors propose a model for assessing the interdependence of the GDPPC and the environmental pollutants production volumes. In this study, the authors built the scenarios for GDPPC growth under environmental constraints by using the idea of Kaya identity. Kaya identity states that total CO_2 emissions are driven by four factors: population size; GDPPC; energy intensity per unit of GDP; and carbon intensity (carbon footprint). This paper analyzed the set of indicators that characterize the state of environmental restrictions and their impact on Russia's GDPPC growth. The authors proved James B. Ang's (2007) findings that pollutants, energy consumption, and outputs are strongly interrelated and therefore their relationship should be further examined under the sustainable framework [21]. The authors agree with I. Korhonen and A. Lyakin, who emphasized in their research that although the current debate focuses on the problems of short-term growth and its stimulation, the problems of long-term growth, taking into account environmental factors, are more significant [22]. The GDP losses in recent years could be mitigated by introducing the following environmental policies: enhancement of environmental investment, improvement of waste management technology, taxation reform for the introduction of waste power generation, and changes in consumption patterns [12].

Similarly, water drains component trends were built-in forecasting the influence of pollutant constraints on the level of Russia's economic development. Their limits are based on the analysis of functions that reflect their relationship and trends for every indicator from 2000 to 2018. For the "wastes" indicators, the value of the limit is taken from the national sustainable goals, aiming to increase the level of waste recycling from 60% to 86%. Regression models have been built to link indicators reflecting the environmental constraints of

GDPPC growth, which have shown a reasonably high level of communication (*R* 2–0.56).

CONCLUSION

It is established that the following trends are characteristic of the Russian economy study period:

(1) With the growth of the population, the level of GDPPC increased, while the energy intensity and carbon footprint decreased;

(2) While economic development increased, energy intensity and carbon footprint are reduced;

(3) Energy intensity was growing when the carbon footprint has grown.

Thus, all the received dependencies are logically not contradictory and statistically reliable. Thus, the authors use indicators reflecting the environmental limitations of Russia's GDP growth and forecasting environmental restrictions for GDPPC until 2030. The use of a research model allowed to manage the level of investments in waste-free production and environmental restoration. The study aimed to understand the structure of conditions and trends in environmental improvement/deterioration. Measuring the ecological footprint as a quantitative assessment of its impact on the growth of the Russian economy is a fundamental condition for understanding the prospects for environmental hazards, and therefore, understanding the sequence of economic and technological measures to preserve the environment.

Research limitations are seen by the authors in the following way: (1) the authors use data for the 2000–2018 period, cause wastes statistics were not full before the 2000s. The study of the product that accompanies

Appendix A

Name	Abbr	Measure
Emissions (Total emitted by stationary and mobile sources)	EMIS	thsnd. ton
Sulfur dioxide	SO_2	thsnd. ton
Nitric Oxide	NO	thsnd. ton
Carbon dioxide	CO_2	thsnd. ton
CO_2 emissions from human-made sources	F	thsnd. ton
Volatile Organic Compounds	VOC	thsnd. ton
Ammonia	NH_3	thsnd. ton
Production and consumption waste generation	PCWG	thsnd. ton
Wastes from production and consumption	W	thsnd. ton
Wastewater discharge	WD	mln. cub.m.
Sulfates	S	mln.ton
Chlorides	Ch	mln.ton
Nitrogen	Ni	thsnd. ton
Nitrates	N	thsnd. ton
Fats and Oils	FAO	thsnd. ton
Phenol	PHE	ton
Plumbum	Pb	ton
Hydrargyrum	Hg	ton
Gross Domestic Product	GDP	RUB bn
Population	P	mln. people
Gross Domestic Product per capita	GDPPC	RUB

Appendix 1 (continued)

Name	Abbr	Measure
Energy consumption	EC	mln. t. of fuel equivalent
incl. Fuel (natural fuel for production)	Fuel	mln. t. of fuel equivalent
incl. Oil	Oil	mln. t. of fuel equivalent
incl. Gas	Gas	mln. t. of fuel equivalent
incl. Coal	Coal	mln. t. of fuel equivalent
incl. Fuel products	FP	mln. t. of fuel equivalent
incl. Combustible by-product energy resources	CER	mln. t. of fuel equivalent
incl. Electric energy	EE	mln. t. of fuel equivalent
incl. Boiler and Heating Fuel	BHF	mln. t. of fuel equivalent
Industrial Production Index	IPI	%
Natural fuel	NF	mln.ton

pollution emissions deserves further theoretical and practical consideration. The results obtained based on the proposed research model could be clarified if, along with statistical information for an extended period, could also be used expert assessments of the indicators limits for better predicting the dynamics of environmental restrictions. The research model for assessing and predicting environmental restrictions should be continued in terms of the initial data reliability; (2) In the system of state statistics, all types of pollutants are estimated in physical and value units of measurement, which limits the possibility of cross-country comparisons; (3) The Russian practice of working with environmental restrictions differs from the practice of developed countries with long-developed market economies, where, along with the numerical values of pollutants, risks of situations that generate the production of pollutants are also recorded. This approach creates an opportunity to prepare and make management decisions about the ecological well-being of the economy to prevent emissions into the atmosphere, polluted water stocks, and production and consumption wastes.

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Steblyanskii N.V. — wrote the theoretical part, performed data analysis.

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