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# Impact of Meteorological Conditions on the Ecological-Economic Systems of Russia

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**ABSTRACT**
Global environmental problems affect all spheres of life, incl. the economic development. As a result, it becomes necessary to study the influence of the environment on economic development, as well as reverse interaction in the form of ecological and economic systems. The climatic factor is of great importance for the state of ecological and economic systems, therefore, when conducting an analysis at the regional level, it is necessary to differentiate the constituent entities of the Russian Federation pursuant to the climatic conditions of agricultural production. The article substantiates changes in the relationship between meteorological conditions and agricultural production, which proves the need to distinguish groups of regions by the climatic factor to assess the level of ecological and economic development. All this will lead to an increase in the effectiveness of measures aimed at environmental and economic development, will help to more efficiently use natural resources and reduce the burden on the environment.
***Keywords:*** *weather conditions, natural environment, environmental-economic system, agricultural production*

## 1. INTRODUCTION

The problem of global climate change continues to evolve, but not all countries of the world have started the fight with full force, and without decisive measures it is impossible to reverse it. As noted in the report on the Sustainable Development Goals: “2019 was the second warmest year on record, ending the warmest decade (2010–2019); it has brought with it massive wildfires, hurricanes, droughts, floods and other climate-related disasters on all continents. By the end of the century, the increase in global temperature may reach 3.2°C. To keep the maximum growth rate stipulated by the Paris Agreement within 1.5°C or at least 2°C, starting from 2020, greenhouse gas emissions shall be reduced by 7.6 percent annually. However, despite the sharp decline in human activity as a result of the COVID-19 crisis, the projected 6 percent reduction in emissions for 2020 is below this target and is expected to rise as the caps are lifted". In the near future, we will also have to face an environmental crisis, especially with the consequences of global climate change. It is necessary to adjust market prices as there are no charges for carbon dioxide emissions and countries do not even estimate their emissions when calculating national revenues. Unless decisive action is taken soon, climate change will far outweigh the current pandemic in its catastrophic consequences. To reduce the risk of uncontrolled climate change, the parties to the Paris Agreement have agreed to keep the global temperature rise within 1.5°C. This requires that global emissions are reduced by 45 percent by 2030 from 2010 levels. However, over the 2000-2018 period, the greenhouse gas emissions in developed countries and countries with economies in transition decreased by 6.5 percent. Herewith, the emissions from 2000 to 2013 increased by 43.2 percent in developing countries. To a large extent, this is due to an increase in the level of industrialization and an increase in the volume of production, expressed in GDP. Climate change has a direct impact on myrrh imports and exports. In particular, an increase in precipitation by 1 mm during the main growing season from May to August in Kazakhstan will increase wheat exports by 0.7% and reduce imports by 1.7%; while a 1°C increase in temperature during the same season will significantly increase wheat exports by 21.9% and reduce imports by 49.4%. Since Kazakhstan is an important global grain trade, the dramatic change in the structure of grain trade as a result of climate change could affect global food security.

In 2017, the decree of the President of Russia, the "Strategy for the Environmental Safety of the Russian Federation for the Period up to 2025" was approved.

The global environmental security challenges in this strategy include "the consequences of climate change on the planet, which inevitably affect the life and health of people, the state of the animal and plant world, and in some regions become a tangible threat to the well-being of the population and sustainable development" and "the growth of consumption of natural resources while reducing their reserves, which against the background of globalization of the economy leads to a struggle for access to natural resources and has a negative impact on the state of national security of the Russian Federation”. As a result, it becomes necessary to study the problems of climate change in connection with the state of the natural environment (NE) and the economy. These relations can be considered within the framework of the ecological and economic system (EES). EES is a NE that is influenced by the economic and social activity of a person, including elements of mutual influence, as well as the resulting consequences.

## 2. METHODOLOGY OF THE STUDY

The analysis is aimed to differentiate the regions of the Russian Federation by the level of development of ecological and economic systems, considering climatic factors. The analysis process can be performed in several stages.

The first stage is to study the nature of meteorological conditions by periods. The data for the analysis were reviewed for 10 years (from 2009-2018). To exclude temperature fluctuations in individual years, it is advisable to study the influence of meteorological conditions by periods: 2009-2013 and 2014-2018. The construction of correlation-regression models will help to establish whether the nature of the influence of meteorological conditions on agricultural production has changed. Assessment of the nature of the interaction may provide for the examination of the effect of the average annual air temperature in July (data for other months in the regional context have not been published since 2013) on the yield of grain crops.

In the Russian Federation, due to the variety of natural and economic conditions, it is advisable to perform the analysis in dynamics, as well as with the differentiation of territories by natural and economic zones and administrative divisions, therefore the second stage is to identify groups of regions pursuant to meteorological conditions. When considering territories, it is necessary to consider the nature and state of information support for the NE and economic activity. Therefore, the analysis is recommended to be performed initially in the context of the constituent entities of Russia, and within them, if necessary, by municipalities. Moreover, it is advisable to separately consider and analyze territories with unfavorable climatic conditions for agricultural activities.

The third stage of the analysis is the calculation of the system of indicators for the selected groups in comparison by periods and years. Thus, it is possible to distinguish groups of regions pursuant to the level of ecological and economic development. In the future, this will help in developing strategies for greening production in the future. For instance, when introducing international standards of the System of Environmental-Economic Accounting (SEEA), adopted in 2012 as an international statistical standard.

## 3. RESULTS OF THE STUDY

Let us consider whether the nature of the weather conditions has changed in recent years. For analysis, let us consider the average data for 2009-2013 and 2014-2018 by regions of the Russian Federation. Analysis of the influence of meteorological conditions on the differences in the value of the yield of grain crops in agricultural organizations in the regions of Russia showed that there is a linear relationship for the 2009-2013 period. The models were built in R using the lmtest package (Figure 1).

```
Call:
lm(formula = dtt2$y ~ dtt2$x1, data = dtt2)

Residuals:
     Min       1Q   Median       3Q      Max
-12.0229  -2.1647  -0.8761   0.9214  24.4500

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 12.94305    0.95254   13.59  < 2e-16 ***
dtt2$x1      0.19434    0.02081    9.34 4.88e-14 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 5.362 on 72 degrees of freedom
Multiple R-squared:  0.5478,    Adjusted R-squared:  0.5416
F-statistic: 87.23 on 1 and 72 DF,  p-value: 4.879e-14

> bptest(dtt2$y~dtt2$x1, data=dtt2)

        studentized Breusch-Pagan test

data:  dtt2$y ~ dtt2$x1
BP = 0.93767, df = 1, p-value = 0.3329

> dwtest(dtt2$y~dtt2$x1, data=dtt2)

        Durbin-Watson test

data:  dtt2$y ~ dtt2$x1
DW = 2.0844, p-value = 0.6357
alternative hypothesis: true autocorrelation is greater than 0
```

**Figure 1** Regression results of the model of dependence of yield on the temperature in July for the 2009-2013 period

Considering the effect of temperature on grain yield, it shall be noted that a 55% yield variation may be due to temperature changes. The model as a whole turned out to be statistically significant (F = 87.23, p-value <1%). Student's t-criterion showed the significance of the parameter (t = 9.34, p-value <1%). The test for heteroscedasticity of the residues (Breusch-Pagan test) showed that homoscedasticity is present in the residues. The autocorrelation test of residuals (Durbin-Watson test) confirmed the absence of autocorrelation in residuals. Therefore, it can be noted that with an increase in the average daily temperature in July by 10°C, the grain yield will increase by 0.19 centner/ha.

The model of dependence of yield on temperature for the 2014-2018 period was built in a similar manner (Figure 2).

```
Call:
lm(formula = dtt2$y ~ dtt2$x1, data = dtt2)

Residuals:
     Min       1Q   Median       3Q      Max
-23.1147  -3.0676  -0.6818   2.0241  22.7037

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  15.4119     1.0962   14.06   <2e-16 ***
dtt2$x1       0.1925     0.0175   11.00   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 6.58 on 72 degrees of freedom
Multiple R-squared:  0.6271,    Adjusted R-squared:  0.6219
F-statistic: 121.1 on 1 and 72 DF,  p-value: < 2.2e-16

> bptest(dtt2$y~dtt2$x1, data=dtt2)

        studentized Breusch-Pagan test

data:  dtt2$y ~ dtt2$x1
BP = 13.76, df = 1, p-value = 0.0002077

> dwtest(dtt2$y~dtt2$x1, data=dtt2)

        Durbin-Watson test

data:  dtt2$y ~ dtt2$x1
DW = 1.5723, p-value = 0.02933
alternative hypothesis: true autocorrelation is greater than 0
```

**Figure 2** Regression results of the model of dependence of yield on the temperature in July for the 2014-2018 period

Pursuant to the model, it can be noted that despite the significance of the equation as a whole (F = 121.1, p-value <1%) and the significance of the parameters (t = 11, p-value <1%), the residuals contain heteroscedasticity (BP = 13.76, p-value <1%) and autocorrelation (DW = 1.57, p-value <1%). Therefore, it is impossible to confirm the revealed dependence and it shall be noted that the relationship between the signs is not linear.

A similar situation is observed when constructing models for selected groups in accordance with meteorological conditions. Thus, it shall be admitted that the nature of meteorological conditions has changed over the periods under consideration. That is, there are processes of changing climatic conditions that affect crop production.
One of the features of the Russian Federation is its vast territory and, as a consequence, the variety of natural and climatic zones. In this connection, during the analysis, the regions with a different standard level of heat supply were grouped pursuant to the average daily air temperature for May-July, and then they (regions) were grouped.
In our country, regions with an average temperature of the growing season of 12.3°C prevail, they account for 85% of the country's territory and a third of agricultural land (34 regions). Group II includes 20 regions with an average daily standard temperature of 15.60°C. Group III included 23 regions with a standard temperature of 18.30°C, respectively. Groups II and III account for only 15% of the country's territory and 62% of all agricultural land.
To characterize natural and climatic conditions, it makes no sense to compare individual years, since there are strong fluctuations in weather conditions. Therefore, for comparison, five-year periods from 2009-2013 and 2014-2018 were considered (Table 1).

**Table 1** Grouping of subjects of the Russian Federation by average daily air temperature for May-July

| Indicators | Region groups | | | Average |
|---|---|---|---|---|
| | 1 | II | III | |
| Number of subjects of the Russian Federation | 34 | 20 | 23 | 77 |
| Average temperature, $C^0$: | | | | |
| July 2009-2013 | 17.3 | 20.5 | 23.5 | 20.0 |
| 2014-2018 | 16.8 | 18.8 | 22.3 | 18.9 |
| Period difference | -0.5 | -1.7 | -1.2 | -1.0 |
| January 2009-2013 | -17.3 | -13.3 | -6.8 | -13.1 |
| 2014-2018 | -15.9 | -11.7 | -5.9 | -11.8 |
| Period difference | 1.4 | 1.5 | 0.9 | 1.3 |
| Amount of precipitation, mm: | | | | |
| July 2009-2013 | 74.2 | 65.4 | 52.4 | 65.4 |
| 2014-2018 | 79.0 | 87.0 | 62.4 | 76.1 |
| Period difference | 4.8 | 21.7 | 9.9 | 10.7 |
| January 2009-2013 | 27.4 | 32.7 | 40.7 | 32.7 |
| 2014-2018 | 31.4 | 39.3 | 44.6 | 37.4 |
| Period difference | 4.0 | 6.6 | 3.9 | 4.7 |
| Average climate productivity score | 105.8 | 128.2 | 134.7 | 120.8 |
| Share,% of the total: | | | | |
| land area | 85.1 | 8.2 | 6.7 | 100.0 |
| Farmland | 37.6 | 22.2 | 40.2 | 100.0 |
| Specific gravity, %: | | | | |
| Farmland in total land area | 5.7 | 34.7 | 77.3 | 12.9 |

Pursuant to the average July temperature, a decrease in the average daily temperature by 10°C can be noted. This could be due to the 2010 heat wave. However, the average January temperatures became higher (by 1.30 °C on average). There was an increase in the amount of precipitation both in July and January, which indicates changes in climatic conditions. The average score of productivity of climate characterizes the group I regions as the least productive. Here, in essence, patchy farming is performed with the specific weight of farmland in the total land area of only 5.7%.

The most economically developed region is group III, with an average climate productivity score of 134.7. In these groups, soil quality and economic conditions for farming are higher. The share of farmland in the total land area is 77.3%. Group II regions occupy an intermediate position.

The development of EES directly depends on heat supply (Table 2).

**Table 2** Characteristics of the constituent entities of the Russian Federation to the level of development of ecological and economic systems

| Indicators | Region groups | | | Average |
|---|---|---|---|---|
| | 1 | II | III | |
| Per person: | | | | |
| Waste-water discharge, $m^3$: 2018 | 102.5 | 94.1 | 67.3 | 88.6 |
| 2009. | 130.5 | 99.0 | 76.7 | 103.7 |
| 2018 to 2009 ratio | 78.5 | 95.0 | 87.8 | 85.4 |
| Air emissions of pollutants from stationary sources, kg: 2018 | 237.8 | 66.7 | 73.6 | 133.7 |
| 2009. | 279.6 | 69.5 | 69.0 | 149.2 |
| 2018 to 2009 ratio | 85.0 | 96.0 | 106.7 | 89.6 |
| Air pollutants captured and neutralized, kg : 2018 | 739.5 | 134.9 | 150.3 | 368.7 |
| 2009. | 798.8 | 217.8 | 157.9 | 419.1 |
| 2018 to 2009 ratio | 92.6 | 61.9 | 95.2 | 88.0 |
| Per 1,000 $km^2$ of area: | | | | |
| Gross regional product, RUR mln: 2017 | 1,844.6 | 10,289.0 | 11,904.3 | 3,211.9 |
| 2009. | 792.5 | 4,424.9 | 4,974.4 | 1,371.2 |
| 2018 to 2009 ratio | 232.8 | 232.5 | 239.3 | 234.2 |
| Air emissions of pollutants from stationary sources, kg: 2018 | 237.8 | 66.7 | 73.6 | 133.7 |
| 2009. | 279.6 | 69.5 | 69.0 | 149.2 |
| 2018 to 2009 ratio | 85.0 | 96.0 | 106.7 | 89.6 |
| Number of enterprises and organizations, units: 2018 | 74 | 736 | 772 | 176 |
| 2009. | 88 | 794 | 832 | 196 |
| 2018 to 2009 ratio | 85 | 93 | 93 | 90 |
| Number of the agriculture, hunting and forestry enterprises and organizations, units: 2018 | 3 | 20 | 31 | 6 |
| 2009. | 5 | 36 | 67 | 12 |
| 2018 to 2009 ratio | 61 | 56 | 47 | 54 |
| Agricultural production, RUR mln: 2018 | 91.1 | 920.6 | 2,340.2 | 309.8 |
| 2009. | 51.2 | 493.7 | 941.6 | 147.2 |
| 2018 to 2009 ratio | 178.0 | 186.5 | 248.5 | 210.5 |

## 4. DISCUSSION OF RESULTS

The regions of group I have the low level of development of ecological and economic systems. Thus, the level of polluted wastewater discharge per person is the highest in the regions of this group (the figure for 2018 is higher than the average for Russia by 16%). Although this indicator has decreased by 21.5% since 2009, it still remains at a fairly high level. Similarly, there is a positive trend in emissions of pollutants into the atmosphere from stationary sources and captured and neutralized pollutants. The level of these indicators relative to 2009 decreased by 15 and 8.4%, respectively, but still exceeds the average value in Russia (by 78% and 2 times, respectively). Per unit area, emissions of pollutants into the atmosphere from stationary sources are of the same nature: a decline relative to 2009, but exceeding the national average.

In terms of the economic level of development, it shall be noted that the regions of group I have gross regional product relative to the land area of 2017 (data for 2018 are not available in the official Rosstat compilations) is almost 2 times lower than the regional average. Herewith, relative to 2009, the GRP has more than doubled. In the regions of this group, there are fewer enterprises and organizations per unit area (more than 2 times lower than the national average). Moreover, the number of enterprises and organizations in agriculture, hunting and forestry is lower (2 times lower). Compared to 2009, the number of enterprises decreased by 15 and 39%, respectively.

Moreover, in the regions of Group I, agricultural production is more than 3 times lower than the average for Russia. That is, the level of agricultural production is significantly lower than the other groups.

The regions that fall into the third group with the highest heat supply have the highest level of ecological and economic development. These regions have the lowest levels of polluted wastewater discharge (24% lower than the national average), emissions of pollutants into the atmosphere from stationary sources (45% lower than the average level), and almost 2 times less air pollutants are captured and neutralized. Compared to 2009, the processes of reducing the negative impact are observed as well. That is, the environmental pollution in these regions is lower than in the rest, despite the high economic development. Thus, the regions of this group have a gross regional product that is 3.7 times higher than the national average. The largest number of enterprises and organizations are located on the territory of the considered regions relative to the area of the territory. And in these regions half of all agricultural products in Russia are produced. There is also a significant increase in production compared to 2009. It shall be noted that cities, especially those with highly developed industries, pollute the atmosphere as a result of a change in the microclimate of the city, which entails a direct change in the temperature of the land surface. In general, it shall be admitted that in the regions of this group, with a high economic load, environmental development also remains at a high level.

Regions of group II occupy an intermediate position. Given a sufficiently high level of economic development, sufficient attention is paid to the state of the natural environment.

## 5. CONCLUSION

Sustainable development shall take into account regional development, economic and social development, as well as the harmonious development of society and nature. Therefore, it is necessary to differentiate the regions of Russia in terms of the level of ecological and economic development, considering the natural and climatic factor in order to increase the stability of the EES functioning.

The analysis performed makes it possible to state that the negative impact on the NE is lower not only in those regions where production volumes are very small, but also in the constituent entities of the Russian Federation with the highest levels of economic development. In economically developed regions, much more attention is paid to the degree of negative impact on NE and protection means. To enhance the efficiency of the country's economy, which will also increase the stability of the EES, it is necessary to restore the country's production potential, increase the intensification of production, as well as restore soil fertility and the livestock industry. All this will lead to an increase in the economic efficiency of the country's agricultural production and will help to more rationally use natural resources and reduce the burden on the environmental protection system.

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