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CARBON LANDFILLS AS A NEW STEP TOWARDS ACHIEVING CARBON NEUTRALITY OF RUSSIAN REGIONS IN THE CONTEXT OF ESG TRANSFORMATION

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ABSTRACT

Objective: The purpose of this paper is to study the possibility of using carbon polygons to achieve carbon neutrality in Russian regions in the context of environmental, social, and governance transformation.

Methods: The authors consider the key principles of ESG transformation, analyze greenhouse gas emissions by sectors of the Russian economy, and assess the potential of carbon landfills as a tool to achieve carbon neutrality. The work uses such scientific methods as historical analysis, case-study method, and structural, comparative, and functional analysis.

Results: The paper presents examples of the implementation of carbon polygons in the regions and an assessment of their potential in achieving carbon neutrality. Quantitative data are systematized following the geographical specifics of the location of carbon polygons, their characteristics, goals, project development scenario, as well as the results of activities in the collection and monitoring of climate data. Practical aspects of the use of carbon polygons in the conditions of ESG transformation are also considered.

Suggestions: The results of the study can be used in the practical activities of regional authorities, enterprises, and organizations dealing with environmental sustainability issues. The theoretical conclusions can be used for further investigation of the carbon footprint problem in the context of ESG transformation. The paper can be used as a guide for the development and implementation of programs to achieve carbon neutrality in Russian regions.

Keywords: Climate change. Carbon neutrality. Decarbonization. ESG policy. Carbon farming, Carbon landfill.

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ATERROS DE CARBONO COMO UM NOVO PASSO PARA ATINGIR A NEUTRALIDADE DE CARBONO DAS REGIÕES DA RÚSSIA NOCONTEXTO DA TRANSFORMAÇÃO ESG

RESUMO

Objetivo: O objetivo deste artigo é estudar a possibilidade de usar polígonos de carbono para alcançar a neutralidade de carbono nas regiões russas no contexto da transformação ambiental, social e de governança.

Métodos: Os autores consideram os princípios-chave da transformação ESG, analisam as emissões de gases de efeito estufa por setores da economia russa e avaliam o potencial dos aterros de carbono como uma ferramenta para alcançar a neutralidade de carbono. O trabalho usa métodos científicos como análise histórica, método de estudo de caso e análise estrutural, comparativa e funcional.

Resultados: O artigo apresenta exemplos de implementação de polígonos de carbono nas regiões e uma avaliação do seu potencial em atingir a neutralidade carbônica. Os dados quantitativos são sistematizados seguindo as especificidades geográficas da localização dos polígonos de carbono, suas características, objetivos, cenário de desenvolvimento do projeto, bem como os resultados das atividades de coleta e monitoramento de dados climáticos. Aspectos práticos do uso de polígonos de carbono nas condições de transformação ESG também são considerados.

Sugestões: Os resultados do estudo podem ser utilizados nas atividades práticas de autoridades regionais, empresas e organizações que lidam com questões de sustentabilidade ambiental. As conclusões teóricas podem ser usadas para uma investigação mais aprofundada do problema da pegada de carbono no contexto da transformação ESG. O documento pode ser usado como um guia para o desenvolvimento e implementação de programas para alcançar a neutralidade de carbono nas regiões russas.

Palavras-chave: Mudança climática. Neutralidade de carbono. Descarbonização. Política ESG. Cultivo de carbono. Aterro de carbono.

LOS VERTEDEROS DE CARBONO COMO UN NUEVO PASO HACIA LOGRAR LA NEUTRALIDAD DE CARBONO DE LAS REGIONES DE RUSIA EN EL CONTEXTO DE LA TRANSFORMACIÓN ESG

RESUMEN

Objetivo: El propósito de este documento es estudiar la posibilidad de utilizar polígonos de carbono para lograr la neutralidad de carbono en las regiones rusas en el contexto de la transformación ambiental, social y de gobernanza.

Métodos: los autores consideran los principios clave de la transformación ESG, analizan las emisiones de gases de efecto invernadero por sectores de la economía rusa y evalúan el potencial de los vertederos de carbono como una herramienta para lograr la neutralidad de carbono. El trabajo utiliza métodos científicos como el análisis histórico, el método de estudio de casos y el análisis estructural, comparativo y funcional.

Resultados: El documento presenta ejemplos de la implementación de polígonos de carbono en las regiones y una evaluación de su potencial para lograr la neutralidad de carbono. Los datos cuantitativos se sistematizan siguiendo las especificidades geográficas de la ubicación de los polígonos de carbono, sus características, metas, escenario de desarrollo del proyecto, así como los resultados de las actividades de recolección y monitoreo de datos climáticos. También se consideran aspectos prácticos del uso de polígonos de carbono en las condiciones de transformación ESG.

Sugerencias: Los resultados del estudio se pueden utilizar en las actividades prácticas de las autoridades regionales, empresas y organizaciones que se ocupan de cuestiones de sostenibilidad ambiental. Las conclusiones teóricas se pueden utilizar para una mayor investigación del problema de la huella de carbono en el contexto de la transformación ESG. El documento se puede utilizar como guía para el desarrollo y la implementación de programas para lograr la neutralidad de carbono en las regiones rusas.

Palabras clave: Cambio climático. Neutralidad de carbono. Descarbonización. Política ESG. Cultivo de carbono. Vertedero de carbono.

INTRODUCTION

The problems of global warming and the growth of greenhouse gas (GHG) emissions, as well as the issues of developing effective tools to reduce climate risks and improve environmental sustainability, are becoming increasingly relevant every year, requiring the search for effective solutions in the context of global environmental, social, and governance (ESG) transformation. The last decades have passed under the sign of a global problem facing humanity as a result of the industrial revolution, i.e. global warming associated with changes in the concentration of GHS, primarily carbon dioxide (CO_2), in the atmosphere during the burning of fossil fuels. Excess CO_2 is trapped in the atmosphere in the form of GHG that heat the planet, changing the climate (Sawyer, 1972).

Long-term forecasts show that anthropogenic factors associated with emissions can lead to critical changes in climatic conditions on the territory of all countries, which will radically affect their economies, including agriculture, energy, and the quality of life of the population.

According to the Third Assessment Report on Climate Change and Its Consequences on the Territory of the Russian Federation (Kattsov, 2022), the territory of Russia is warming almost twice as fast as the land as a whole.

Effective impact on climate change requires transformational changes in all sectors of the economy, including decarbonization of global energy and food systems (Harper et al., 2018; Houghton et al., 1992; Schulte et al., 2022).

As a result of the ongoing climate changes, the term "carbon neutrality" has emerged, which means maintaining CO_2 emissions at the level of those volumes that nature can absorb independently, with the help of forests and oceans.

To date, more than 120 countries have already set strict targets for reducing GHG emissions, and more than 60 countries have declared a goal of achieving carbon neutrality by 2050-2060. After the world's largest economies have assumed such obligations, the scientific community is trying to determine the measures necessary to achieve this goal (Iqbal et al., 2021; Nurgaliev et al., 2021; Safi et al., 2021; Schulte et al., 2022; Sychev & Naliukhin, 2021). The transition to zero emissions, in addition to improving the environmental sustainability of the global ecosystem, can also open up significant opportunities for economic growth, not only in the low-carbon sector but also in other economic spheres, leading to the transformation of the entire global economy.

In this context, the development and testing of technologies for controlling GHG emissions, as well as calculating the carbon balance of territories, are becoming especially relevant for Russia. Thus, the purpose of this study is to evaluate the possibility of using carbon polygons to achieve carbon neutrality in Russian regions in the context of ESG transformation.

LITERATURE REVIEW

In the first half of the 20th century, many scientists conducted research on the regulation of global climate change, which at that time was primarily associated with the possibility of a new ice age. Global warming at that time was not considered a serious problem. Scientists paid more and more attention to the fact that the cause of negative trends was human activity (Arrhenius, 1908; Chamberlin, 1899; Pigou, 1920).

In 1950-1970, many scientists considered the problems of studying global warming in their works, including G. Suss and R. Revill (1957), who performed an analysis of CO_2 emissions and their absorption by the ocean. By the end of the 1950s, scientists were increasingly insisting that the problem of CO_2 emissions was becoming global. According to some forecasts, the level of CO_2 for the period from 1959 to 2000 was supposed to increase by 25%, having a radical impact on the climate.

Based on the United Nations (UN) environmental program established in 1972, in 1983, the concept of sustainable development was introduced, implying development in which current generations could meet their needs without jeopardizing the opportunities of future generations in this. In 1987, the UN Report "Our Common Future" formulated the conceptual principles of sustainable development, containing three interrelated areas that are considered as a single whole, i.e. ESG areas. ESG is based on three components according to which companies strive for sustainable development.

In the modern context, the terms "sustainable development" and "ESG" are often used synonymously. Sustainable development is rather a general concept and philosophy expressed in the UN Sustainable Development Goals, and ESG is more a reflection of business efficiency on the way to achieving the goals set.

In this paper, we focus on one of the components of ESG policy, namely, the environmental component, which consists of several areas: climate change; water resources management; emissions, collection, waste, and resource use; biodiversity and land resources; environmental compliance.

The legal basis for cooperation on climate change issues between countries is the UN Framework Convention, which was executed in New York in 1992. Later, in 1997, the Kyoto Protocol was adopted as an additional document to the Framework Convention, which includes several provisions that the countries that ratified the agreement were obliged to comply with:

1. Improving the efficiency of energy use in the relevant sectors of the national economy;
2. Protection and improvement of the quality of absorbers and accumulators of GHG, promotion of rational methods of forestry and reforestation;
3. Promoting sustainable forms of agriculture in the light of climate change considerations;

4. Conducting research, promoting the implementation, development, and wider use of new and renewable types of energy, CO_2 absorption technologies, and innovative environmentally friendly technologies;

5. Measures to limit and reduce GHG emissions in the transport sector.

In 2006, under the leadership of the British economist N. Stern, a comprehensive report "The Economics of Climate Change" was published (Stern, 2006), which became an important step that determined the further vector of low-carbon development. The report substantiates that in the 21st century, anthropogenic GHG emissions were the main cause of climate change, and the main danger they entailed was the shortage of fresh water.

The authors of the report note that adaptation to climate change is a necessary measure, but the problem can be solved only by drastically reducing the emissions. The measures to reduce them should be aimed at switching demand towards low-carbon products and services, improving fuel and energy efficiency, developing and implementing low-carbon technologies, CO_2 capture and disposal, and changing land and forest management.

One of the ways aimed at reducing the share of GHG in the atmosphere is the capture of CO_2 with the help of natural ecosystems. To implement this technology, so-called carbon polygons, and carbon farms are being created. In the last few years, the issue of social, economic, and environmental results from their creation has been actively discussed in the scientific literature.

Carbon landfills are land plots where technologies for controlling the production and absorption of GHG are developed and tested, and the speed of photosynthesis of different plants is studied. Carbon farms are plantations, and plots of land on which these GHG absorption technologies are applied in practice.

The idea of creating carbon polygons is a feature of the Russian approach to achieving carbon neutrality. In global practice, CO_2 absorption technologies are tested on conventional farms, without the allocation of special territories. The Russian Federation, due to its geographical features, is characterized by a certain natural and climatic uniqueness and diversity of individual regions and localities, which explains the creation of special polygons for different natural conditions. This approach makes it possible to adapt the implemented technologies to environmental conditions and increase their efficiency.

Studies of carbon polygons are based on the experience gained in Russian and foreign practice.

In the scientific works of foreign authors devoted to the issues of CO_2 capture from the atmosphere through forest ecosystems, the term "carbon farming" is more often used, implying a set of agricultural methods aimed at separating carbon in ecosystems: in soil, wood, and plant environment, usually in agricultural landscapes (Efremova, 2022; Evans, 2018; Kragt et al., 2017; Reth et al., 2005). In a broad sense, carbon sequestration technologies through the creation of carbon landfills and farms can also be attributed to carbon farming.

Y.-J. Shin et al. in their research note that the most urgent and interrelated problems facing humanity in the modern context are climate change and loss of biodiversity. The authors propose a set of measures aimed at restoring the natural balance and reducing carbon emissions, including through terrestrial and marine ecosystems, and also pay attention to the uneven territorial distribution of biodiversity, which requires spatial planning measures to maintain the ecological functioning of territories (Shin et al., 2022).

G. Harper (2014) in his works draws attention to the fact that carbon farming aimed at capturing CO_2 from the atmosphere and mitigating the effects of climate change will make it possible to convert CO_2 into another industrial product, for example, biofuels, and use it in other processes, which will have a significant impact on the ecological development of individual territories.

In many research papers, authors identify several positive effects achieved with land use based on low and negative emissions, which manifest themselves not only in the environmental component but also carry some socio-economic benefits for the regions (Colvin & Przybyszewski, 2022; Green & Gambhir, 2020; Lehtonen et al., 2022; Wan et al., 2021).

K. Tang et al. in their study write not only about the environmental benefits of carbon farming, manifested in improving water quality, soil health, and protecting biodiversity, but also about the economic benefits that accompany them, such as fighting poverty, food security, benefits for public health, and improving infrastructure. As a result of the research, the authors conclude that the concomitant benefits from the development of carbon farming created a significant additional motivation for farmers to engage in carbon plantations (Tang et al., 2016).

Many Russian scientists also pay attention to the combination of environmental and economic benefits for the regions where carbon landfills are being created. For example, S.S. Morkovina et al. (2021) in their work "Economic aspects of the organization of carbon farms on forest lands" write that despite the significant financial costs of creating carbon farms, this step is necessary and entails many economic and environmental benefits, such as climate improvement, increased fertility, development of ecosystem services, as well as the opportunity to provide support for enterprises with a carbon footprint.

In the work "Creation of forest carbon polygons: the economic component", E.A. Panyavina (2021) draws attention to the economic benefits achieved as a result of carbon polygons: "Carbon polygons will allow controlling the carbon balance in the country, will affect the improvement of the environmental situation, and will also contribute to increasing the economic benefits of entrepreneurs by producing more competitive products" (p. 26).

Thus, researchers agree on the effectiveness of carbon farming and the creation of carbon landfills, both in combating global environmental problems and in influencing the socio-economic development of regions and territories as a whole.

Many authors think that the introduction of carbon polygons can create possible negative effects, leading, for example, to an increase in land clearing and the emergence of monocultural plantations (Evans et al., 2015). Hence, it can be concluded that the development of carbon farming and the creation of carbon farms within national ecosystems will be more effective if these projects are focused on obtaining a wider range of benefits than only environmental ones, namely, in the field of CO_2 sequestration.

METHODS

We used the following research methods:

- historical analysis, i.e. study of the evolution of approaches to overcoming the consequences of global climate change and regulating emissions of various kinds of waste, to the emergence of technologies for sequestering GHG;

- the case study method, i.e. a study of the features of the formation and development of carbon polygons in Russian practice, as well as the social, economic, and environmental effects of their functioning;

- structural analysis, i.e. identification of factors determining the specifics of carbon polygons, and design scenarios of their functioning;

- comparative analysis, i.e. identification of common features and differences of existing Russian landfills, common and different in the tools they use to solve the problem of GHG emissions in Russian regions;

- functional analysis, i.e. identification of the correlation between the spread of carbon polygons and the achievement of carbon neutrality goals.

RESULTS AND DISCUSSION

The manifestation of climate change on the territory of the Russian Federation is characterized by a significant diversity and ambiguity of consequences not only for the natural environment but also for the economy and the population as a whole. In this regard, a comprehensive approach to all risks and opportunities caused by observed and expected climate changes is important for Russia. This introduces specific features into the climate policy of the Russian Federation both at the federal and regional levels.

When implementing a green policy, a clear understanding is needed of what is the current carbon balance of the country; that is, where and in what quantity the emission and absorption of GHG are carried out. At the moment, the Russian economy demonstrates fairly high GHG emissions, which are presented by sectors of the Russian economy in Table 1.

Table 1. GHG emissions by sectors of the Russian economy (million tons of CO_2 equivalent per year)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Energy	1,639.3	1,687.3	1,694.5	1,625.2	1,617.1	1,611.3	1,606.1	1,637.0	1,688.7	1,682.3	1,597.7
Industrial processes and use of industrial products	197.8	201.1	217.2	221.4	221.7	219.1	218.0	230.9	240.2	233.6	241.7
Agricultural industry	103.5	106.2	105.2	107.7	107.5	108.6	112.3	113.2	112.8	114.0	116.6
Land use, land use change, and forestry	-720.4	-663.4	-685.9	-631.6	-668.1	-590.0	-609.0	-603.5	-584.5	-559.0	-569.2
Waste	71.3	74.5	76.9	79.5	82.8	85.0	87.0	89.1	91.0	92.9	95.4
Total, excluding land use, land use change, and forestry	2,011.9	2,069.0	2,093.9	2,033.8	2,029.1	2,024.0	2,023.4	2,070.2	2,132.7	2,122.8	2,051.4
In total, taking into account land use, land use change, and forestry	1,291.5	1,405.6	1,408.0	1,402.2	1,361.0	1,434.0	1,414.5	1,466.8	1,548.2	1,563.8	1,482.2

Source: compiled by us based on the data provided by the Federal State Statistics Service (2022).

The main share of emissions includes CO_2, methane (CH_4), and nitrous oxide (N_2O), which prevent long-wave solar radiation from leaving the climate system.

The current situation creates obvious risks for Russian businesses and the economy. In the absence of a comprehensive state policy on the decarbonization of Russian industry, Russian exports, characterized by high carbon intensity per unit value and ahead of leading countries in this indicator (Fig. 1), run the risk of having to pay high carbon taxes. Moreover, in the future, we can talk not only about the products of the metallurgical, chemical, or cement industry but also about a wider range of export products, including agricultural ones.

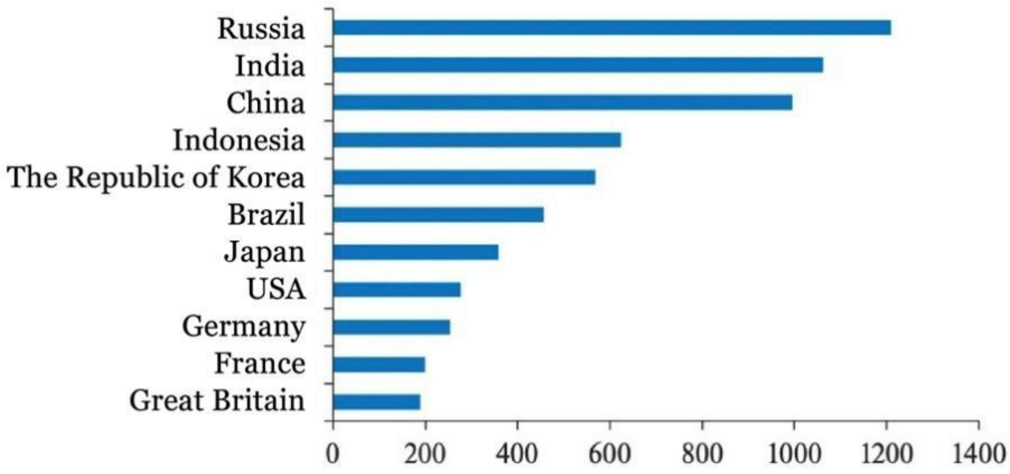

Figure 1. The level of the carbon intensity of exports of the largest countries of the world economy in 2015, CO_2/million dollars (Ivanov & Durmanov, 2021)

One of the methods of removing CO_2 from the atmosphere is its biological sequestration, that is, absorption within ecosystems by plants, soils, and water masses.

To assess the balance of GHG flows for various ecosystems in Russia and the development of technologies aimed at sequestration of GHG, a two-year pilot project of the Ministry of Science and Higher Education of the Russian Federation "on the creation of landfills for the development and testing of carbon balance control technologies as specially equipped terrain areas" has been launched.

Carbon polygons are areas of the earth's surface with relief, soil, and plant composition characteristic of a given territory, where GHG emissions and absorption are monitored, the state of natural ecosystems, the quality of water resources, and other parameters are assessed.

As of March 2023, 17 carbon landfills were launched in Russia, represented in each of the eight federal districts (Karbonovye poligony Rossiiskoi Federatsii, n.d.). Table 2 shows an analysis of the number of polygons relative to federal districts.

Table 2. Analysis of the number of carbon polygons in Russia by federal districts

Federal District	Central Federal District (CFD)	North-West Federal District (NWFD)	North Caucasian Federal District (NCFD)	Volga Federal District (VFD)	Ural Federal District (UFD)	Siberian Federal District (SiFD)	Far Eastern Federal District (FEFD)	Southern Federal District (SoFD)
Number of polygons	4	1	1	2	4	2	2	1
Share of the total	24%	6%	6%	12%	24%	12%	12%	6%
Area of the federal district in km^2	650,200	1,687,000	170,439	1,038,000	1,789,000	4,362,000	6,953,000	447,900
Number of km^2 per polygon	162,550	1,687,000	170,439	519,000	447,250	2,181,000	3,476,500	447,900

Source: compiled by us based on Karbonovye poligony Rossiiskoi Federatsii (n.d.)

To create a complete picture of the carbon balance of the whole country, it is necessary to cover all representative ecosystems of Russia. The vast territory of Russia provides unique opportunities for modeling various climatic zones. The main part of Russia is located in the temperate zone, the northern mainland regions and islands of the Arctic Ocean are in the Arctic and subarctic zones, while the Black Sea coast of Russia is in the subtropical zone.

Today, in absolute values, the distribution of carbon polygons across federal districts is not yet uniform, and the standard deviation is about 11%. The largest share of carbon polygons is represented in the CFD and UFD: their share is 24% in each of all polygons in the Russian Federation, while the smallest one is represented in the NWFD, NCFD, and SoFD with 6% in each one. If we consider the ratio of the area of the federal district to the number of carbon polygons in it, we can see that their distribution becomes even more uneven. The standard deviation, in this case, will be 983,784 km^2. Carbon polygons have the greatest coverage in the CFD and the NCFD, while the FEFD has the smallest territory. It can be concluded that the largest amount of research resources is currently observed in the CFD and the smallest one in the FEFD.

To cover the whole country, 80 carbon landfills are planned to be launched in the future, which will create a reliable system for controlling the emission and absorption of GHG.

In 2021, at the St. Petersburg Economic Forum, the President of Russia announced a key task for carbon polygons to systematize the measurements carried out on them to obtain retrospective data for at least 5-10 years to build high-quality carbon balance models.

The main tasks of the polygons were defined in the report of the Ministry of Education and Science of the Russian Federation "Carbon polygons, pilot project: results of the first year". Russian carbon landfills are the result of the integration of federal and regional authorities, scientific organizations, higher education institutions, and industrial and technological partners. The industrial partners undertake obligations to co-finance the carbon landfill, while the technological partners contribute to the development of technologies and the organization of research and practical process at the carbon landfill.

The range of functions of carbon polygons is extremely wide. It includes assessment of GHG emissions and absorption by ecosystems, creation and testing of technologies for measuring aboveground and underground phytomass, agrochemical soil studies, remote sensing using space and unmanned platforms, development of mathematical models for calculating the carbon balance of ecosystems, and much more. The main characteristics, goals, and areas of the scenario for the development of Russian carbon polygons are summarized in Table 3.

Table 3. Main characteristics, goals, and areas of the project scenario of Russian carbon polygons

Polygon name/ location/ year of opening/ area	**Carbon neutrality goals**	**Project scenario**
Chashnikovo (Moscow region, 2021) 605.9 Ha	Development of low-carbon environmental management strategies, reforestation, and agronomic technologies	Monitoring observations; assessment of variability of GHG emissions and absorption; development of technologies; highly productive plantings; restoration of lands and forests
BioCarbon (Novosibirsk Region, 2021) 1,008 Ha	Economically efficient introduction of unclaimed agricultural land into circulation with the use of sustainable land use technologies	Forest restoration; regenerative agriculture and animal husbandry
Eurasian Carbon landfill (Republic of Bashkortostan, 2022) 11,599.5 Ha	Development of monitoring methods; assessment of GHG emissions by ecosystems and enterprises; study of the possibility of carbon deposition; search for optimal decarbonization solutions	Monitoring observations; assessment of variability of GHG emissions and absorption; remote monitoring technologies; highly productive plantings; restoration of lands and forests; restoration of swamps; regenerative agriculture and animal husbandry
Carbon-Volga region (Republic of Tatarstan, 2021) 60 Ha	Assessment of GHG deposition emissions; data collection, validation, and processing system; creation of sequestration technologies	Highly productive plantings; restoration of lands and forests; regenerative agriculture and animal husbandry
Ural-Carbon (Sverdlovsk Region, 2021) 606 Ha	Development of assessment methods and assessment of carbon stocks and flows	Monitoring observations; assessment of variability of GHG emissions and absorption; technology development; remote monitoring technologies; highly productive plantings; restoration of lands and forests; personnel training
Tyumen carbon landfill (Tyumen Region, 2021) 10,670 Ha	Assessment of GHG emissions and deposits; methodology for accounting for carbon credits	Monitoring observations; assessment of variability of GHG emissions and absorption; technology development; remote monitoring technologies; highly productive plantings; land restoration; regenerative agriculture and animal husbandry; personnel training
Mukhrino (Khanty-Mansiysk Administrative District, 2022) 1,573.4 Ha	Long-term observations of GHG flows; assessment of the carbon balance of forest and swamp ecosystems	Monitoring observations; assessment of variability of GHG emissions and absorption; land restoration
WAY CARBON (Chechen Republic, 2021) 1,785 Ha	Creation of climate change models and methods of accounting for GHG emissions and absorption; determination of carbon deposition volumes by terrestrial ecosystems; data collection, validation, and processing system	Monitoring observations; assessment of variability of GHG emissions and absorption; technology development; remote monitoring technologies; highly productive plantings; forest restoration
Sem listvennits (Yamalo-Nenets Autonomous Okrug, 2022) 2,395 Ha	Control of the human carbon footprint and the absorption capacity of ecosystems; methodological support of climate projects; leadership in the development of low-carbon solutions for the Arctic	Monitoring observations; assessment of variability of GHG emissions and absorption; restoration of lands and forests
FOR&ST CARBON (Voronezh Region, 2022) 181.3 Ha	Development of technological solutions for carbon balance control; testing the absorption capacity of forest and steppe ecosystems; obtaining economically valuable and climate-resistant forest crops	Monitoring observations; Assessment of variability of GHG emissions and absorption; Technology development; Remote monitoring technologies; Personnel training
Rosyanka (Kaliningrad Region, 2021) 255.4 Ha	Quantitative estimates of GHG flows. Obtaining data on seasonal and daily variability of GHG flows. A system for monitoring changes in the nature of GHG flows	Development of carbon sequestration technology in the marine environment. Land restoration. Regenerative agriculture and animal husbandry
Kaluga (Kaluga Region, 2021) 600 Ha	Conducting systematic studies of CO_2 emissions and the general state of the region's ecosystems	Monitoring observations; assessment of variability of GHG emissions and absorption; technology development; personnel training
Tomsk carbon landfill (Tomsk region, 2022) 450 Ha	Creation of scientific and educational infrastructure for the development and testing of CO_2 control technologies in the region	Monitoring observations; assessment of variability of GHG emissions and absorption; land restoration; personnel training
Carbon-Sakhalin (Sakhalin Region, 2021) 4,004 Ha	Launch of regular monitoring of the state of the region's ecosystems, development of a strategy to achieve carbon neutrality	Development of carbon sequestration technologies; integrated geographical information system (GIS) measurements
Gelendzhik (Krasnodar Territory, 2021) 26 Ha	Development of carbon sequestration technology; monitoring of CO_2 emissions and development of a decarbonization strategy	Highly productive plantings; restoration of lands and forests; regenerative agriculture and animal husbandry
Carbon landfill of the Higher School of Economics	Monitoring of GHG flows in the studied ecosystems to assess the carbon balance. It is planned to build the first Russian prototype of a	Selection of the best plants that absorb CO_2 most efficiently, creation of models for digital remote monitoring of biomass,

(Moscow, Kaluga, and Kirov regions, 2023) 1,830 Ha	combined monitoring system for the agroforestry ecosystem of carbon farming	development of the concept of the carbon farming industry, and the organizational and legal model of a carbon farm
Carbon landfill in Primorsky Territory (Primorsky Territory, 2023) 304.23 Ha	No data available since the landfill was launched in the 1st quarter of 2023	No data available since the landfill was launched in the 1st quarter of 2023

Source: compiled by us based on Karbonovye poligony Rossiiskoi Federatsii (n.d.)

Carbon landfills should become not only monitoring sites but also begin to implement the possibilities of experimental landscape modification to assess the effectiveness of the absorption potential of various types of ecosystems. Such experimental work may include sowing highly sequestering crops, changing the type of soil, and exploring the potential of mariculture and other technologies. The most successful of them will later become climate projects developed by the industrial partners of the landfills. A full evaluation of the results of the monitoring system using polygons will be possible in a decade, although many key assessments will appear and be used in 3-4 years.

The analysis of the activity of carbon polygons involves considering the diversity of their tools. The set of equipment may vary depending on the tasks and the location of the carbon landfill. There are basic types of equipment characteristic of most carbon polygons. These include stations for analyzing the gas composition of the atmosphere by the method of turbulent micro-vortex pulsations; systems for measuring soil gas exchange; systems for measuring plant gas exchange; analyzers for measuring the level of dissolved inorganic carbon in marine and fresh waters.

To date, much attention in the activities of carbon polygons is paid to scientific research and educational developments, thanks to which, it was possible to achieve results in the field of scientific and methodological tools for conducting climate monitoring, including work on the creation of geoinformation and digital maps of polygons and individual sites. Field studies and experiments related to the collection of climate data are actively conducted on the territory of the landfills (Table 4). At each of the polygons, measurements of the flows of the main climatically active gases, heat, and moisture flows are provided based on pulsation and chamber methods, as well as a direct emission from the soil surface. Measurements are provided by a network of ground sensors, as well as remote observations using unmanned aerial vehicles equipped with the necessary set of sensor equipment such as multi- and hyperspectral cameras, radars, lidars, etc. The composition and configuration of measuring instruments depend on the characteristics of the polygon itself.

Table 4. The results of the activities of carbon polygons for the collection and monitoring of climate data

Polygon name	Results of climate data collection and monitoring activities
Chashnikovo	A GIS polygon system has been created. Digital models of terrain and relief. Instrumental year-round monitoring, including an accounting of meteorological parameters, GHG emissions, etc.
BioCarbon	Digital terrain models. Map of the normalized difference vegetation index (NDVI). Information about the composition and characteristics of ecosystems. Verification of the carbon balance of the region. Development of a strategy for managing the carbon balance of the region.
Eurasian Carbon landfill	The installation locations for the GHG flow measurement towers have been determined. Investigation of heterogeneity of vegetation cover and collection of samples. Topography of the forest area. Geoinformation map of swamp complexes.
Carbon-Volga region	High-resolution orthophoto maps. Clarification of the location of the water section. Selection of thermotolerant algae culture. Primary determination of the carbon stock in the biomass of trees. Phytoplankton development in the water area.
Ural-Carbon	Partial aerial photography. Processing of atmospheric satellite sensing data. Characteristics of gas exchange. Assessment of plant respiration, soil. Estimates of the capacity of carbon pools. Suggestions for plants for farms.
Tyumen carbon landfill	Digital polygon frame. Equipment of the measuring complex. Methodology for assessing the sequestration potential of a single sheet. Protocol of indicators of the plant sequestration potential.
Mukhrino	Collecting data on the climate and carbon balance of the swamp complex. Estimation of CO_2 flows. High-resolution remote sensing data collection. Determination of the dominant functional groups of peat organic matter, etc.
WAY CARBON	Meteorological data base. A series of integrated maps of agro-climatic conditions of steppe landscapes. Analysis of modern climatic conditions of semi-desert landscapes. Software for monitoring and accounting of GHG emissions based on GIS, etc.
Sem listvennits	No data available since the landfill was launched in the 4th quarter of 2022.
FOR&ST CARBON	Quantitative estimates of CO_2 absorption by trees. Microclones of tree species for the data bank. Collections of tree species for obtaining planting material. Adaptation of vegetative reproduction methods. Technical requirements for planting material of forest crops.
Rosyanka	The landfill currently carries out year-round monitoring of the natural and anthropogenic systems of the region and is also developing technology for sequestering GHG emissions that are handled by rotting algae and marine debris.
Kaluga	Investigation of methods for increasing the absorption capacity of CO_2 on agricultural lands, monitoring of CO_2 emissions in various conditions, as well as a comprehensive assessment of the volumes of aboveground phytomass using specialized software.
Tomsk carbon landfill	At the moment, the polygon performs basic measurements.
Carbon-Sakhalin	A project has been implemented to assess the full cycle of absorption and utilization of CO_2 emissions from the carbon cycle using various types of algae and shellfish.
Gelendzhik	Autonomous measuring systems located at the landfill providing hydrophysical, hydrochemical, and bio-optical data with high spatial and temporal resolution.
Carbon landfill of the Higher School of Economics	No data available since the landfill was launched in the 1st quarter of 2023.
Carbon landfill in Primorsky Territory	No data available since the landfill was launched in the 1st quarter of 2023.

Source: compiled by us based on Karbonovye poligony Rossiiskoi Federatsii (n.d.)

Each carbon landfill, created in partnership with universities and scientific organizations, has its own unique research agenda and educational mission.

The implementation of climate projects requires specialists who are beginning to be trained at Russian universities. The interdisciplinary nature of the GHG monitoring task requires the involvement of specialists from various fields, such as meteorology, climatology, oceanography, modeling, measurement technology, etc.

In addition, Russian carbon landfills are actively involved in international cooperation programs through cooperation with foreign experts, exchange of measurement data, and joint research (Lanshina et al., 2021).

This is fundamentally important for the coverage and recognition of the research results of scientific groups of polygons, partner universities, and research institutes abroad. An important result of the activity of the polygons will be the exchange of scientific data based on the measurements carried out. The publication and discussion of such results will increase the reliability of conclusions about the carbon sequestration potential of the territories of Russia, as a result of which the methods of calculating the export carbon tax on the products of Russian companies may be revised.

Scientists and experts have already been included in the expert council on carbon landfills. Scientists from China, India, Serbia, Iran, the UAE, and Egypt have officially confirmed their readiness for cooperation (Ministry of Science and Higher Education of the Russian Federation, 2022).

The observations carried out at the landfills will be integrated into international observation and research programs.

Further development of the network of Russian carbon landfills is associated with some limitations that need to be overcome shortly. These include the increased difficulty of access to advanced technologies necessary to equip both existing and planned carbon landfills, as well as difficulties in attracting business and expanding extra-budgetary financing for this project.

If we talk about technological limitations, today the supply of equipment continues, but with an increase in terms and an increase in cost by 20%-30% (Ministry of Science and Higher Education of the Russian Federation, 2022).

Further sustainable development of carbon landfills in Russia depends on the level of equipment supplied by the national manufacturer. At the moment, active work is underway to replace imported equipment, including within the landfills themselves. For example, one of the landfills is developing and commissioning Russian-made gas analyzers. Active work is underway to develop Russian analogs, for example, for devices for the pulsation method of measuring CO_2 flows, and Russian-made software is being developed.

Certain steps have also been taken to overcome financial constraints at the expense of extra-budgetary funds. Financing individual projects is up to one-third of non-state investments. For example, the Tyumen carbon landfill was financed for 187.75 million rubles by the state and 82 million rubles (more than 43% of the state financing and 30% of the total) were extrabudgetary funds. For the Gelendzhik carbon landfill, extra-budgetary financing accounted for more than half of the total, equaling 53.5%, 184 million attracted against 160 million state funds. Extra-budgetary funding for the Ural-Carbon landfill exceeded budget funding by more than 2 times (260.2 million against 126.6 million of state funds). Currently, there is a positive trend of expanding the number of industrial partners representing large businesses interested in the sustainable development of the Russian economy.

Summing up, we would like to note that the implementation of such a large-scale and unique project to develop a network of carbon landfills, the result of joint efforts of the state, business, and the scientific community, is a serious step towards the formation of a national system for monitoring and controlling GHG emissions and absorption, which serves as the basis for solving the problem of decarbonization of the Russian economy.

CONCLUSION

We conclude that Russia's commitments to participate in the climate agenda necessitate the development of tools to reduce GHG emissions and the development of climate projects, including those aimed at increasing the sequestration (absorbing) capacity of forest cover. In this regard, it becomes important not only to develop algorithms and methods for monitoring and estimating GHG emissions, but also to create real production facilities and carbon farms aimed at implementing the set plans, which in the future will give in many sectors and types of economic activity of the Russian economy.

The development of carbon landfills and farms in Russia can become a promising tool in the control of global environmental problems and have a positive socio-economic impact on the development of Russian regions.

a) The environmental benefits include control of the CO_2 balance of various climatic zones in the country, improvement of the ecological situation, soil quality and fertility, protection, and growth of biodiversity, and increase in crop yields.

b) The economic benefits include new sources of tax deductions, economic benefits for enterprises due to the production of competitive products, the growth of farm incomes, the development of a Russian-made carbon balance calculation system, and the possibility of additional support for enterprises with a carbon footprint.

Affecting various economic spheres, such as energy, transport, agriculture, industry, etc., carbon landfills can create a synergistic effect in the future, increasing the efficiency of the use of economic resources.

c) The social benefits will be expressed in strengthening the country's food security, benefits to public health and infrastructure, and income growth of the population. Since higher education institutions participate in the creation of carbon polygons and farms, we can talk about additional social benefits in the form of creating new areas of study for the training of specialized personnel in this field, which in the future will entail the creation of jobs in a new field, giving opportunities for professional development in this area.

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