# Carbon polygons: greenhouse gas monitoring methods

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**Abstract**. The study of carbon polygons and their role in greenhouse gas dynamics is of paramount importance in the context of climate change and global environmental concerns. Carbon polygons, also known as peat plateaus or peat polygons, represent unique ecosystems found in northern regions, which play a significant role in the global carbon cycle. These landscapes consist of a mosaic of waterlogged polygon centers and elevated rims, characterized by diverse vegetation and complex hydrological processes. One of the key concerns regarding carbon polygons is their potential to release greenhouse gases, primarily methane and carbon dioxide, into the atmosphere. As global temperatures rise and permafrost thaws in northern areas, these ecosystems become critical focal points for scientific research and monitoring.

## 1 Introduction

According to the current international practice, carbon farms are in the foreground as a promising area of activity for natural absorption and removal (sequestration) of GHGs. In the current international practice, carbon farms are in the foreground as a promising area of activity for natural absorption and removal (sequestration) of GHGs. In the EU, it is recognized that carbon farms are "a green business model that helps owners and management to improve land management, which translates into increased carbon sequestration in living biomass, dead organic matter and soil by reducing carbon sequestration and/or reducing emissions of carbon into the air" [1]. Carbon-based farms are expected to help achieve the EU climatic goal, in support of the Common Agricultural Policy and programs such as LIFE6 or Horizon Europe, as well as private projects on carbon products (climate project) In 2022, legislative proposals will be made in the EU to confirm "carbon" withdrawals, as a result of reliable and transparent monitoring and verify. It is also possible to see another example of Australia's Carbon Farms Roadmap8, the roadmap that intends to create new jobs by 2030 and increase state revenues. During the same time, there are still many questions regarding stability and reliability of results obtained for carbon farms. Since the start of 2021, the Ministry of Science and Higher Education launched a two-year pilot project to create test sites for carbon balance control systems as specially prepared regions in seven regions: the Chechen Republic, Krasnodar Territory, Kaliningrad Region, Novosibirsk region, Sakhalin Region, Sverdlovsk Region

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and Tyumen Regional9. As of 2022, there were 15 landfills operating in Russia with an area of 39.2 hectares and the total area of them was 392,000 hectares. Carbon polygons will cover all representative ecosystems of Russia, to clarify the carbon balances. [2]. The operation landfills account for more than a quarter of Russian ecosystems (Fig.1). To cover the whole country, their number should be 80. The Russian Ministry of Education and Science has calculated that in order to completely fill out all the education systems for the entire country, it is recommended that the number of students will increase to 80.

In Russia, carbon polygons are created on the basis of universities and scientific institutions (operators), with industrial and technological partners. The budgetary support is received by economically-based organizations (operators) that have participated in the development of Carbon polygons. Organizations-technological partners will organize its scientific and practical activities by co-financing the carbon landfill, organizations-industrial partner undertake to co-finance the carbon landfill, organizations-industrial partners - to finance it. The Expert Council, under the Ministry of Education and Science in Russia on scientific support for developmenting carbon balance control technologies, provides coordination and methodological support to develop the network of Russian landfills. At the same time, it considers proposals for creating new landfills (inclusion in an pilot project requires Expert Council's opinion) and determines performance measures and evaluate them.

## 2 Research Methodology

Carbon polygons, also known as peat plateaus or peat polygons, are critical ecosystems for understanding greenhouse gas dynamics and carbon sequestration in northern regions. These unique landscapes exhibit a complex mosaic of waterlogged, unvegetated polygon centers surrounded by elevated rims dominated by mosses, lichens, and vascular plants. They play a significant role in the global carbon cycle and the potential release of greenhouse gases into the atmosphere, particularly methane and carbon dioxide (fig.1).

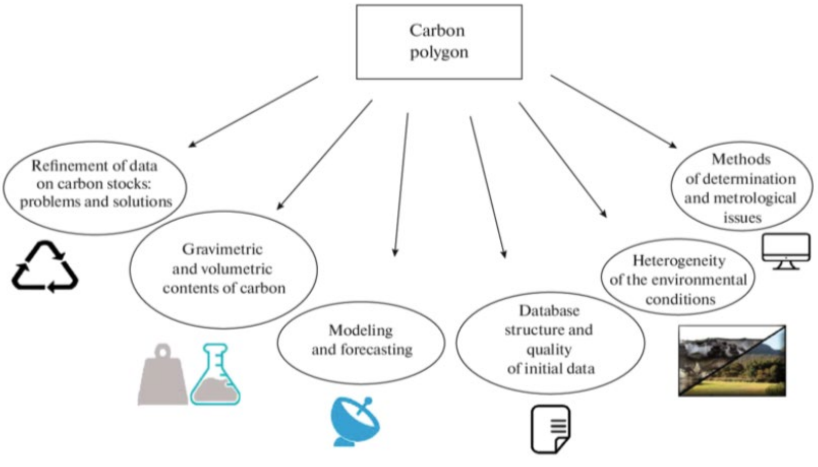


**Fig. 1.** Areas of application of data obtained from carbon polygons.

To monitor greenhouse gases effectively within carbon polygons, various research methods are employed, enabling scientists to gain valuable insights into the intricate processes occurring within these ecosystems:

Gas Flux Measurements: Continuous monitoring of methane and carbon dioxide fluxes is conducted using chambers, eddy covariance towers, or automated gas analyzers to assess the exchange of these gases between the ground surface and the atmosphere.

Soil Sampling and Analysis: Soil cores are collected to measure the concentration of carbon and nutrients in polygon soils, helping researchers understand the role of these substrates in greenhouse gas production and consumption.

Geospatial Technologies: Remote sensing techniques, including satellite imagery and aerial surveys, provide valuable data on polygon distribution, vegetation cover, and changes in land use, aiding in the assessment of carbon dynamics.

Isotope Analysis: Stable isotope analysis allows for the differentiation of methane produced by microbial activity in the polygon centers, helping identify the sources of greenhouse gases.

Microbial Community Profiling: DNA sequencing and molecular techniques enable scientists to study the microbial communities in carbon polygons and their role in greenhouse gas production and consumption.

Permafrost Assessment: Investigating the thermal state and stability of permafrost beneath polygons is essential in understanding potential future carbon release.

Climate and Meteorological Data: Monitoring weather conditions and climate parameters in and around carbon polygons provides critical context for greenhouse gas dynamics.

Long-Term Monitoring: Establishing permanent field sites and research stations for continuous data collection over extended periods is crucial to track changes in greenhouse gas emissions.

Eddy Covariance Flux Towers: These towers provide real-time data on the exchange of greenhouse gases between the surface and the atmosphere and are particularly useful for quantifying carbon dynamics.

Methane and Carbon Dioxide Profiling: Gas profiling systems enable detailed measurements of gas concentrations at multiple depths in polygon soils, allowing researchers to assess vertical profiles of greenhouse gas dynamics.

Remote Sensing of Vegetation: Utilizing remote sensing technology to monitor changes in plant communities and their effects on carbon and methane cycling.

Incorporation of Hydrology: Understanding the hydrological processes and water table fluctuations within carbon polygons is essential to greenhouse gas monitoring.

Sediment Core Analysis: Analysis of sediment cores from polygon centers provides historical records of greenhouse gas emissions, aiding in the assessment of long-term trends.

Modeling and Simulation: Advanced modeling approaches are employed to simulate greenhouse gas fluxes under different climate scenarios, helping predict future trends.

Ground-Penetrating Radar (GPR): GPR technology is used to assess permafrost properties, polygon structure, and depth to the water table.

Gas Trapping Techniques: Portable gas traps and chambers are employed to capture and analyze greenhouse gases emitted from polygon soils under controlled conditions.

Carbon Balance Calculations: Researchers calculate the carbon balance in carbon polygons by considering all sources and sinks of carbon, enabling a comprehensive assessment of their role in the global carbon cycle.

Geochemical Analysis: Assessing the geochemical characteristics of polygon soils and sediments helps elucidate their role in greenhouse gas dynamics.

Land-Atmosphere Interaction Studies: Investigating the interactions between carbon polygons and the atmosphere provides insights into the overall contribution of these ecosystems to the carbon cycle.

Community Engagement: Collaboration with local communities and indigenous peoples is crucial for gathering traditional knowledge and understanding the cultural significance of these ecosystems, which can enhance research efforts and the protection of carbon polygons.

By employing these diverse methods, scientists can obtain a comprehensive understanding of greenhouse gas dynamics in carbon polygons, contributing to the broader knowledge of climate change and its implications for northern ecosystems and the global carbon cycle.

## 3 Results and Discussions

Russian carbon landfills will contribute to the formation of an reliable national system for monitoring GHG flows in the country's ecosystems and the carbon cycle [7]. The development of a reliable national system for monitoring GHG flows in the country's ecosystems and carbon cycle should be supported by the construction of new systems for monitoring GHG flow. Among the main tasks of carbon farms is to determine, develop and implement economically and climatic-efficient solutions for the sequestration (sequessorting) of GHG by natural ecosystems in Russia. The Ministry of Education and Science has identified the 12 as the main tasks of carbon landfills: − assessment of spatial variability from GHG gases and its consequences over time intervals; − development and adaption of technology that will control GHG emission or rejection through ground-based data and model methods on the basis of an effective methodology for monitoring the structure and condition of vegetation and cover, GHG energy losses and decreases with the help of computerized techniques for controlling them, such as determining integral value points at different territories over specific periods under real conditions, as well as training of highly qualified personnel in the field of low-carbon industry, agro-industrial production, industrial use and other factors. CSR surveyed the landfills, as well as other landfills that have been assessing carbon balance of its ecosystems, see the goal in assessing the carbon balance of them and creating technologies. At the same time, a number of them also show up in terms of practical aspects. For example: the search for optimal solutions to decarbonization and methodological support on climate projects are included in this list; obtaining economically valuable and climate-resistant forest products, as well as acquiring economically valuable and climatic-resistant forest crops. As a result of this, the main tasks defined by the Russian Ministry of Education and Science are relevant for them all over the world. The main tasks defined by the Russian Federation Ministry of Education and Science are important for them.

In different regions of Russia, carbon polygons are located in the same place and represent different kinds of landscapes and ecosystems [8]. They can be represented by one site or consist of several sites that characterize individual ecosystems. It is possible to represent them in a single site or consist of several sites that characterize individual ecosystems. It is known that the plots of the surveyed polygons are sized from 2 ha to 10,670 h (Guzeneyevo nature reserve in Tyumen region). The size of the plots of the surveyed polygons vary from 2 ha to 10,670 ha (Guzeneyevo nature reserve in the Tyumen region). In Chuvash Republic, the area of a landfill planned for an industrial site may exceed 200,000 ha.

The leading scientific and educational centers of the country act as operators of the carbon polygons, which actively involve other research teams, including institutes of the Russian Academy of Sciences. As a rule, landfills are supported by industrial partners, which are represented by large businesses operating in the region and interested in sustainable development. For example, PJSC SIBUR participates in two surveyed carbon landfills - in the Tyumen and Voronezh regions. The presence of industrial partners enhances the practical orientation of the landfill, which is primarily expressed in the implementation of climate projects at carbon farms. The technology partners of the carbon landfills, in turn, contribute to the development of technologies and new solutions.

Russian carbon polygons pay great attention to scientific work aimed at the development of scientific and methodological tools in the field of climate monitoring, including work on the creation of geoinformation and digital maps of polygons or individual areas. Field studies and experiments are also closely related to the development of scientific and methodological tools. Separately, one can also single out the assessment and calculation of the carbon balance. Thus, the scientific research carried out on the territory of the Russian carbon polygons can be conditionally divided into three categories [9]:

1. Development of scientific and methodological tools in the field of climate monitoring: - measurements, as well as their processing and analysis of their results; − modeling; − creation of geoinformation and digital maps (systems).

2. Field studies and experiments: - scientifically based selection of crops and species; − agro- and forest-climatic experiments; − development of science-based requirements and proposals.

3. Estimation and calculations of the carbon balance

A fairly wide range of technologies is being developed and (or) tested at Russian carbon ranges, which can be divided into four categories:

1. General technologies: − software and technologies for monitoring GHG emissions and removals; − software and technologies for estimating and modeling the emission and absorption of GHG emissions.

2. Agricultural technologies: - technologies of carbon-negative and ecological plant growing; − technologies for increasing the efficiency of crop production (use of various fertilizers and their analogues). Source: CSR survey data (9 active polygons, excluding Seven Larches) 4 polygons 6 polygons 8 polygons Carbon balance assessment and calculations Field studies and experiments Scientific and methodological monitoring tools. Forestry technologies: − technologies of inexhaustible forest management; − technologies for increasing the absorptive capacity of forests.

3. Technologies for obtaining carbon-neutral products (biochar, hardly decomposable biochar).

The most common are the technologies and software used to observe and model GHG emissions and removals. In fact, such technologies are used to some extent at all surveyed landfills. Scientific and (or) educational activities carried out at the landfills require the collection of data both for preliminary analysis and for evaluating the results of such activities [10]. Technologies that are being tested and (or) developed for use in agriculture and forestry are widely used. The main objectives of the development of these technologies are to increase the efficiency of the relevant types of activities, as well as their decarbonization (reducing GHG emissions / increasing the absorptive capacity of ecosystems). In addition, landfills are often used to develop technologies for producing various carbon-neutral products, which can subsequently be used, including in agriculture and forestry. As a result, the development of complementary technologies contributes to the formation of mini-clusters on the basis of landfills (for example, obtaining carbon-neutral fertilizers to increase the efficiency of crop production). To measure GHG fluxes at carbonic landfills, it is proposed to use an integrated approach based on both ground-based and remote observation methods, namely: − systems for measuring greenhouse gas fluxes in natural ecosystems (towers, gas analyzers, unmanned systems); − meteorological equipment; − laboratory analytical equipment.

International cooperation of carbon polygons in connection with the initial stage of their implementation is focused on conferences, publications in foreign journals and internships.

The aggravation of the geopolitical situation in 2022 significantly complicated it, as traditional ties with foreign partners, especially from Western countries, were broken. The survey allows us to conclude that a number of contacts are still maintained (for example, with Japan, India) and that further reorientation to Asian countries and a focus on cooperation within the EAEU can be expected. Thus, the carbon range on Lake Kuchak (Tyumen region) was singled out as a key international partner by the East Kazakhstan Technical University. D. Serikbaeva (Kazakhstan) [11]. Polygon Source: CSR survey data (9 operating polygons, excluding Seven Larches) 6 polygons 6 polygons 9 polygons To develop this area, the polygons offer to maintain existing (and potentially restore broken ties), develop cooperation with Asian countries, organize international conferences and projects in Russia, and facilitate payment for participation in foreign conferences and publications in foreign journals. Encouraging in this regard is the invitation of foreign experts to the Expert Council under the Ministry of Education and Science of Russia on scientific support for the development of carbon balance control technologies. The Ministry of Education and Science of Russia announced at the beginning of September, 2022 about existence of officially confirmed readiness for cooperation from scientists from China, India, Serbia, Iran, the United Arab Emirates and Egypt [12].

Among the current barriers, most landfills cite access to technology (eg delayed supplies or lack of domestic equivalents) and funding (eg weak business incentives). Quite often, polygons mark infrastructure access (such as network connectivity) and administrative barriers. Administrative barriers include the complexity of procedures for obtaining permits for conducting climate research in specially protected areas, the lack of standards and common methods for conducting measurements, as well as common formats for data exchange and storage. To overcome the current barriers, taking into account the survey data, the following can be proposed:

− assistance in attracting technological and industrial partners to the landfills;

− stimulating the development of domestic instrument base and equipment;

− development and improvement of national standards and methodologies in the field of climate monitoring and GHG measurements;

− development and improvement of the legislative framework for the implementation of climate projects in the field of forest relations;

− development and improvement of national standards in the field of creation of carbon sequestering plantations;

− organization of training events and coordination of the process of exchange of experience and best practices between the landfills. In addition, the following directions for optimizing the development of the entire network of carbon polygons in Russia were proposed:

− development of methodological recommendations for the selection of new observation sites (polygons), including from the point of view of expanding the representativeness of the entire network of polygons;

− publication of samples of the best observing programs and (or) lists of current priorities for conducting observations (a set of mandatory, accompanying and confirming observations);

− operational inclusion of used instruments in the state register of measuring instruments;

− development of protocols for processing, storing and exchanging data, including the organization of a single center for processing and storing data obtained at landfills. Among the potential barriers, access to funding is most often mentioned, but uncertainty with the verification of the obtained data is also mentioned (in particular, devices without certificates can be used in current studies)

## 4 Conclusions

In conclusion, carbon polygons have emerged as crucial tools in the effort to monitor and understand greenhouse gas dynamics in various ecosystems. These monitoring methods have provided valuable insights into carbon sequestration by forests and other land uses, contributing to our understanding of the global carbon cycle and climate change. By using a combination of remote sensing technologies, ground-based measurements, and modeling approaches, researchers can better assess carbon fluxes and their impacts on global warming. This knowledge is essential for informed decision-making and the development of effective climate policies.

The study of carbon polygons also highlights the need for continued research and innovation in greenhouse gas monitoring methods. Ongoing advancements in technology and data analysis will enable more accurate and comprehensive assessments of carbon dynamics in various ecosystems. Furthermore, international collaboration and data sharing are critical to improving our understanding of the global carbon cycle and addressing climate change challenges.

Carbon polygons, as a research focus, underscore the urgency of mitigating greenhouse gas emissions to combat global warming effectively. These findings emphasize the importance of implementing sustainable land management practices and policies to enhance carbon sequestration and reduce greenhouse gas emissions. As the world faces the consequences of climate change, the study of carbon polygons provides valuable insights and tools for mitigation and adaptation efforts.

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