Использование технологий информационного общества

CARBON MEASUREMENT SUPERSITES IN RUSSIA: USING INFORMATION TECHNOLOGIES TO TRACK RESEARCH TRENDS (2014–2024)

Статья рекомендована к публикации главным редактором Т. В. Ершовой 18.03.2025.

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Abstract

Understanding greenhouse gas dynamics helps assess emissions, develop monitoring strategies, improve land management, and work toward carbon neutrality. To support research, carbon measurement supersites have been established worldwide. In Russia, a network of these supersites was launched in 2021. This study identifies key research areas using topic modeling to analyze articles from major Russian digital libraries. Fifteen significant topics were found, with their dynamics from 2014 to 2024 assessed. Experts detailed each topic, highlighting the role of supersites in strengthening Russia's position in carbon regulation and trade. Expanding their regional impact is recommended.

Keywords

carbon measurement supersites; topic modeling; carbon–related topics; carbon regulation; greenhouse gases

https://doi.org/10.52605/16059921_2026_01_141

Introduction

Despite considerable efforts by the global community, it is not yet possible to stop global warming. According to the annual "Greenhouse Gas Bulletin," atmospheric CO2 levels in 2023 experienced a notable increase compared to 2022. This was due to the ongoing reliance on fossil fuels, widespread forest fires, and a potential decrease in carbon sequestration by forests. It is noteworthy that the annual increase of 2.3 parts per million represents the 12th consecutive year in which the increase has exceeded 2 parts per million [1]. Although substantial investments have been made in mitigation research and action, the success of climate policy still depends on a more comprehensive understanding of carbon–climate feedback, including an understanding of greenhouse gas dynamics in different ecosystems [2].

Understanding the dynamics of greenhouse gases in different ecosystems contributes to assessing the balance of these gases and sources of emissions, developing monitoring strategies, improving land management, and moving toward achieving carbon neutrality. Therefore, scientific centers – supersites – have been established in different regions of the world to monitor terrestrial and aquatic ecosystems [3]. The supersite network complements remote monitoring from space or unmanned aerial vehicles and it is driven by a need to study the dynamics of all types of greenhouse gas ecosystems in the region. Supersites have been previously used to address scientific issues and proved effective for aggregating global data, understanding measurement methods [4], using common tools, protocols, and standards across sites, minimizing maintenance costs [5], conducting experiments, and achieving synergies with other research programs [6]. In addition to addressing research issues related to pollution monitoring, supersites are also used to study ecosystems [7]. For example, TERN (The Terrestrial Ecosystem Research Network) is designed to monitor ecosystems in Australia and focuses on three research areas such as landscape observation, ecosystem observation, and ecosystem processes [3]. TERN monitors essential characteristics of terrestrial ecosystems over time, from the continental scale to field sites at numerous representative locations. The organization freely shares data that is ready for use in models, allowing researchers to detect and analyze changes in ecosystems [8]. Similarly, the need to study the balance of greenhouse gases in territories with natural and socioeconomic features encourages the use of the supersite format and all its advantages.

In the Russian Federation, the decision to create a network of carbon measurement supersites (in Russia these sites are more commonly referred to as ‘carbon polygons’) was taken by the Ministry of Science and Higher Education in February 2021 [9]. The initiative aimed to create a network of research plots that accurately represent the relief, vegetation, and soil cover structure of the given territory. These plots are intended to develop scientific, educational, personnel, and infrastructural potential in the field of elaborating and testing technologies aimed at monitoring the balance of climatic active gases of natural ecosystems. Some supersites were created based on already existing research centers. For example, in 2009, the UNESCO Chair ‘Environmental Dynamics and Global Climate Change’ at Yugra State University established the field station ‘Mukhrino’, which was further transformed into a supersite [10]. In March 2020, a pilot supersite was launched in the Kaluga Region within the Ugra National Nature Park for a research project led by the Ministry of Science and Higher Education [11]. To date, there are 19 supersites with a total area of 312939.53 Ha [12].

The primary objective of carbon measurement supersites is to measure and monitor greenhouse gas fluxes. In addition, these supersites facilitate research into the potential of greenhouse gas absorption in various ways, promote educational activities, and foster international collaboration. The operations at carbon measurement supersites adhere to standards for measuring and monitoring the characteristics of the carbon cycle in natural ecosystems. For this purpose, standardized tools, protocols and standards are developed, ensuring compatibility with the system of international measurements.

Thus, supersites were established at different times, they are located in different natural zones and are associated with different scientific centers. Therefore, the activities of Russian carbon measurement supersites encompass a wide range of research areas in natural sciences, law, engineering, economics, industry, agriculture. It is challenging to evaluate the overall picture of the research conducted at supersites, i.e. to identify the principal areas of research and under–researched areas, and to ascertain whether the obtained results align with the goals and priorities established for Russian supersites. To address these issues, it is crucial to analyze the content of publications related to carbon measurement supersites using the methods of computer topic modeling. Topic modeling allows analyzing textual information and identifying hidden thematic structures in a collection of documents. The article aims to identify key research areas related to the topic of carbon measurement supersites. Through topic modeling, the article will also clarify the content of the main thematic clusters derived from the analysis of scientific publications. Based on the results of topic modelling, it is possible to identify promising research areas and tasks solved by researchers related to the topics of carbon measurement supersites. To our

knowledge, there have been no review articles focusing on carbon supersites that include publications in Russian. Therefore, our study is the first to review Russian–language publications published since 2014 and included in the largest Russian digital libraries.

1 Method

Topic modeling was used to analyze texts of articles focusing on carbon–related topics. Topic modeling has proven effective in mining large text corpora. In this method, a topic model processes a collection of documents, attempting to reveal the underlying topics within the set without supervision. Each identified topic corresponds to a human–interpretable semantic concept. Topic modeling thereby offers a latent, interpretable representation of documents based on the identified topics [13].

1.1 Data collection

For this study, we collected a set of Russian scientific articles related to the topic of carbon measurement supersites. The data sources utilized were the digital libraries Elibrary[1] and Cyberleninka[2], which were selected due to their status as two of the largest and most widely used digital repositories of scientific articles in Russian[14].

The articles were retrieved using the search query "carbon measurement supersites" ("карбоновый полигон"). The search was conducted in a semi–automated mode, and the collected articles span the years 2014 to 2024. Data collection was completed in early November 2024. For each article, we documented the title, list of keywords, abstract, and publication year, as these details are publicly available for all publications. The distribution of articles by year presented in Figure 1.

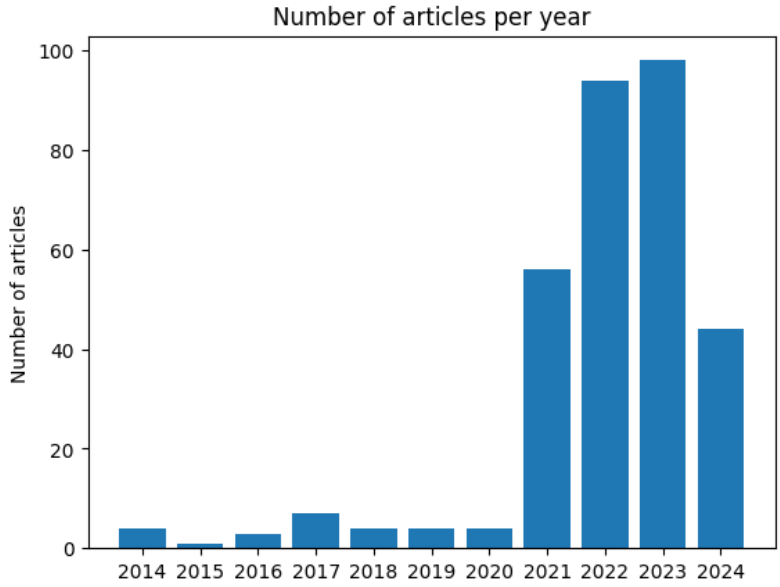

Fig. 1. The distribution of articles by year.

The figure illustrates a gradual increase in the number of articles on this topic, with a notable rise starting in 2021.

Training topic models required preprocessing of the source data. First, the title, keywords, and abstract of the article were consolidated into a single text. Next, special characters and stop words were eliminated from the texts and lemmatization was performed using the pymorphy2 library [15]. The texts were checked for duplicates. The total number of the collected texts was 319, with an average length of 1452.17 symbols per text. The final text sample included 220 texts obtained from the CyberLeninka library and 99 texts obtained from Elibrary.

1.2 Topic modeling

There are numerous topic modeling methods, but not all of them are widely used. Commonly applied methods include algebraic approaches (LSA, NMF), probabilistic methods (LDA), and neural network-based techniques (LDA2Vec, BERTopic). Modern neural network-based methods rely on pre-trained large language models, which

[1] https://elibrary.ru
[2] https://cyberleninka.ru

utilize contextualized word vector representations built on large text corpora. As modern research shows, incorporating neural components is usually advantageous [13]. Pre-trained linguistic models allow for capturing not only the statistical characteristics of word co-occurrence frequencies but also the semantic component. This study employed the BERTopic model [16], which leverages word vector representations from pre-trained language model called BERT model (Bidirectional Encoder Representations from Transformers) [17], applies clustering procedures with dimensionality reduction, and ranks the words that form topics. Topic modeling in BERTopic involves three main steps. First, each document in the collection is converted into a vector representation using the paraphrase–multilingual–MiniLM–L12–v2 model [18]. These embeddings capture not just the lexical meaning of words, but also their context, helping to account for polysemy and complex semantic relationships between words. Next, the dimensionality of these vectors is reduced with UMAP (Uniform Manifold Approximation and Projection), facilitating more efficient clustering through the HDBSCAN (Hierarchical Density-Based Spatial Clustering of Applications with Noise) algorithm. Dimensionality reduction helps visualize and group the texts while preserving the key patterns and relationships between them. HDBSCAN handles data with varying densities and can identify noise points (texts that don't fit into any cluster). Finally, key phrases (n-grams) specific to each cluster are identified with a customized c–TF–IDF metric, which aids in clearly defining the topics represented by each cluster. BERTopic also provides tools for visualizing the results, so researchers can better understand how topics are distributed across the text corpus.

BERTopic is widely used for topic modeling of texts across a diverse range of subjects and languages, including Russian–language texts. In particular, in the study [19], the BERTopic model was applied to analyze topics in a corpus of legal documents. The authors highlight the potential of topic modeling for interdisciplinary research and emphasize the importance of the results for both computational linguistics and legal studies. Study [20] employs BERTopic for analyzing user reviews and demonstrates its effectiveness in addressing the problem of corpus-based mining of opinion aspects. The study [21] applies topic modeling to identify hidden communities of social media users. The authors use BERTopic because it demonstrates high effectiveness across corpora of different genres, and its integrated contextualized BERT model accounts for polysemy.

The following parameters were used for BERTopic: a minimum topic size of five texts, an n-gram range spanning from one to three, and the extraction of ten words per topic. As a result of topic modeling, 15 significant topics were identified in the text collection (Fig. 2): 1 – climate policy; 2 – carbon dioxide in the soil; 3 – landscape; 4 – geochemistry of carbon; 5 – monitoring sites; 6 – greenhouse gas emissions from waste; 7 – ecosystem; 8 – monitoring methods; 9 – carbon dioxide in the atmosphere; 10 – carbon dioxide in the water; 11 – supersites; 12 – collaboration; 13 – nature–based solution project; 14 – land use type; 15 – ESG project.

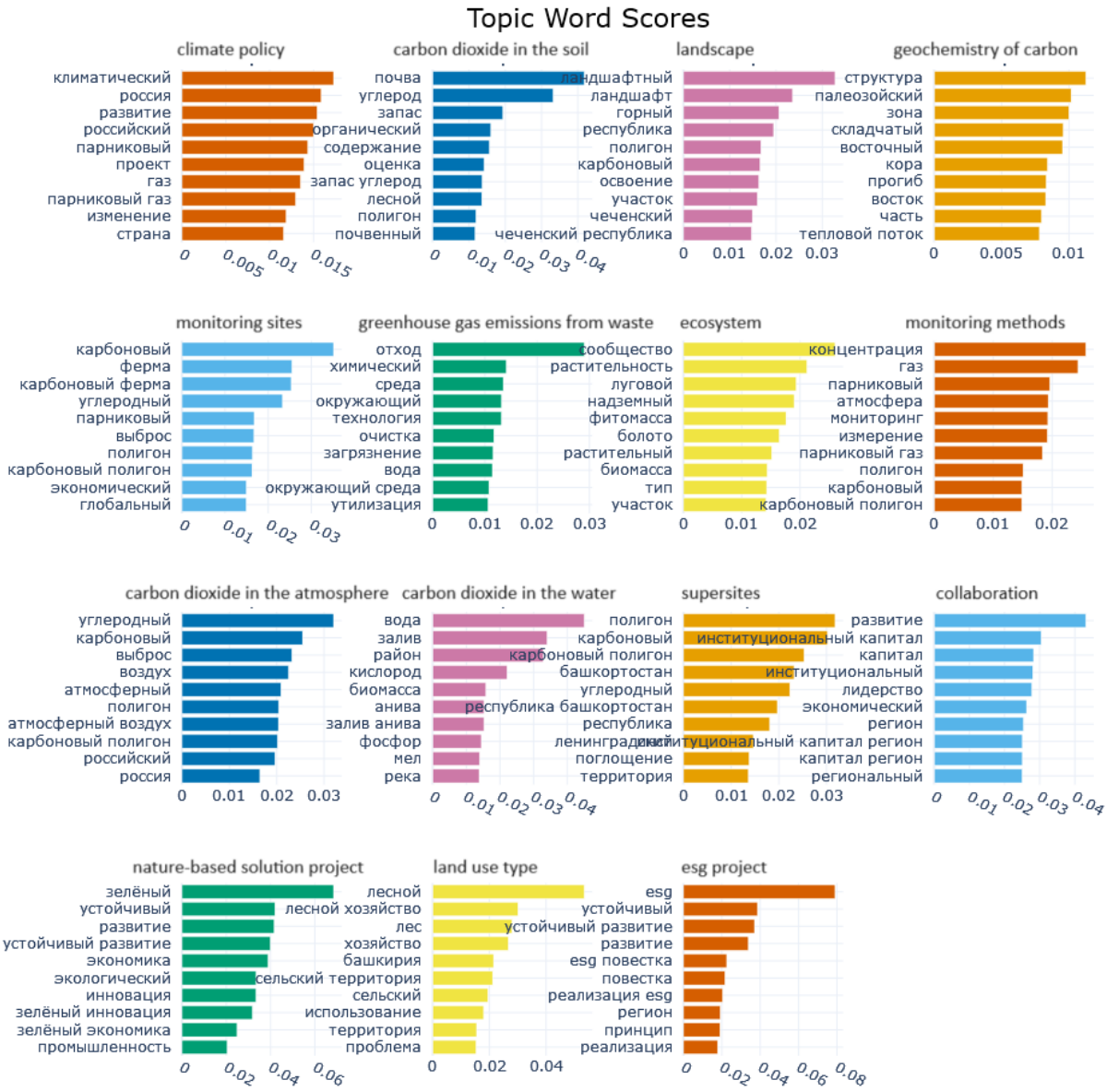

Fig. 2. Identified topics.

The topics were labeled by researchers from the Carbon Measurement Test Area in Tyumen's Region based on the key phrases specific to each topic.

2 Results and Discussion

The analysis of publications has shown that since 2021 there has been a rapid increase in the number of publications associated with the launch of pilot carbon measurement supersites in the Kaluga Region and Tyumen Region, as well as with the plans of the government of the Russian Federation to create a network of research centers [12]. In addition, this period has witnessed the adoption of key climate-related laws and strategic documents, leading to an intensification of public discussion on climate policy [22,23]. Ten of the fifteen identified topics have only been observed since 2021 to 2024, while few studies related to monitoring greenhouse gases have been published since 2014.

The analysis of the distribution of articles by topic confirms a predominant focus on carbon stocks and flows in soil, water, and atmosphere, on the carbon balance in various ecosystems, and the development of projects to adapt to and mitigate anthropogenic impacts on the climate. The topics are listed below in order of their frequency.

2.1 Climate policy

The topic includes 29 articles published between 2018 and 2024. This is the highest number of publications, which might be due to Russia's active transition to low–carbon development initiated in 2018. The 2020 Presidential Decree set the goal of limiting greenhouse gas emissions to 70 percent of 1990 levels by 2030 [24] with plans for carbon neutrality set for 2060 [23]. Climate policies are driven both by the Russian government's response to the global climate change agenda and by concerns regarding the potential economic impact of a carbon tax on international trade [25]. As a result, an expert dialogue has emerged within the country to align national interests with the climate agenda [26]. Some researchers have noted that while Russia is a northern nation characterized by high fuel consumption, it also possesses significant carbon sequestration potential due to its diverse ecosystems and advancing technologies [27]. Carbon measurement supersites have been proposed as venues for testing both carbon sequestration potential and technologies [28]. The ongoing dialogue has highlighted challenges in implementing climate policies, particularly the absence of regulated reporting mechanisms for carbon measurement supersites, which can lead to inefficient allocation of budget resources [27]. Some scholars dispute the significance of carbon neutrality goals, and they express skepticism stating that other environmental issues in Russia also require urgent attention beyond the reduction of greenhouse gas emissions [29].

2.2 Carbon dioxide in the soil

The topic includes 28 publications from 2021 to 2024, which are related to studies of the carbon balance in the soil cover under various landscape and geochemical conditions [30]. These studies were conducted at carbon measurement supersites; for example, one study in the Republic of Tatarstan assessed the total and microbial carbon content and the abundance of microorganisms in sod-podzol soils in the southern taiga subzone [31]. Another study described primary calculation materials to estimate soil sequestration capacity, the distribution of carbon in different pools and soil profiles, alongside laboratory data on the emissions of CH4, CO2 and H2O gas flows [32]. The study of different soil types revealed a decrease in total carbon content at deeper horizons along the soil profile. Additionally, other researchers analyzed the factors that influence the dynamics of carbon in soil, such as climate parameters, variations in stable carbon isotope composition, and physicochemical properties of soil. This analysis led to conclusions regarding the predominance of climatic or intra–soil factors in the dynamics of organic matter [33].

A significant number of publications showed the procedure of studying anthropogenically transformed soils, including agricultural landscapes. For example, researchers have demonstrated that the introduction of peat substrate rich in nutrients and plant propagules during biological rehabilitation significantly enhances the accumulation of organic matter increasing carbon storage and CO2 emissions from the replanted soil surface [34]. In addition, some papers contained descriptions of various validated methods for estimating net carbon dioxide emissions. Some articles provided results of testing new research methods, mathematical or cartographic modeling. Blocks of mutually complementary maps allow estimating the total reserves and the ratio of the main pools of organic carbon in soil thickness from 0–30 cm, applicable both for the whole territory of the country and for specific regions in the European part of Russia [35].

2.3 Landscape

This topic includes 18 articles that explore the morphological characteristics of landscapes, carbon balance in ecosystems, and the assessment of carbon in anthropogenically transformed systems. Within landscape complexes, unique conditions are formed that determine carbon dynamics. Researchers have investigated these conditions to elucidate contrasts in carbon dynamics at different levels of landscape differentiation [36]. This is most noticeable in mountain ecosystems and altitudinal belts, as confirmed by studies conducted on a carbon transect in high–mountain territories of Chechen Republic. Different land use types in anthropogenic landscapes also differ in conditions for carbon accumulation and in carbon dynamics. Understanding these conditions and dynamics is crucial for characterizing different scenarios of greenhouse gas emissions and sequestration in different types of landscapes. By focusing on the relationship between the landscape and its use, researchers not only predict the carbon accumulation scenario, but also assess the sustainability of the landscape when implementing certain technologies [37]. In addition, researchers have highlighted that the use of remote sensing data facilitates the study of landscape diversity and makes it possible to more accurately assess the contribution of landscapes to the greenhouse gas balance [38]. A number of studies have analyzed the geochemical functioning of landscapes, such as the assessment of dissolved organic matter transformation, which is essential for understanding local and global carbon cycling [39].

2.4 Geochemistry of carbon

The topic includes 18 publications from 2014 to 2024 that investigate geological and paleogeographic causes of greenhouse gas emissions and accumulation. One notable area of research is the gas saturation in permafrost rocks [40]. Research in this area has primarily focused on gas emissions during drilling into permafrost rocks or on previously unexplored processes, such as subsidence sinkhole formation [41]. The study of geological structures within the context of carbon policy was mainly limited to analyzing geological formations under the conditions of intense gas release [42].

Significant attention has been paid to using geological formations for the storage of carbon dioxide, and for this purpose, the option of arranging carbon dioxide storage within the Moscow Artesian Basin is currently under consideration. The study has resulted in the zoning of the Moscow Artesian Basin in terms of suitability for long–term CO2 storage, with the identification of 16 geological structures with medium–term potential [43].

2.5 Monitoring sites

The topic includes 18 publications that describe the locations where research is conducted such as research stations, fields, types of carbon measurement supersites. One of the types of supersites is an agricultural carbon test site, where technologies to reduce greenhouse gas emissions in agriculture are developed [44]. If the effectiveness of agricultural technology is proven, it can be used for reducing carbon tax on agricultural products or for carbon trading [45]. Research has also highlighted another type of supersite known as carbon farms, which are designed to quantify and validate the amount of carbon uptake by plants, algae, and bacteria [46]. Carbon farms serve as long-term research platforms, creating mathematical models to facilitate understanding the response of agrocenoses to increasing concentrations of greenhouse gases in the atmosphere in order to develop better methods of cultivation. Given its significant carbon sequestration potential, Russia is believed to have an opportunity to successfully develop carbon farming. Some studies focused on the impact of carbon farms on the regional economy [47]. In the process of developing carbon farms, researchers faced the lack of standards for measurements, methodologies for calculating carbon sequestration, and regulatory frameworks for organizing such activities [46]. There are separate articles devoted to the optimization of the observation network of carbon measurement supersites [48].

2.6 Greenhouse gas emissions from waste

This topic contains 17 publications that have been published since 2014. Oil production and petrochemicals are pivotal sectors of the Russian economy. Decarbonization of the industry includes technologies for the utilization of waste associated with the oil industry [49]. In addition, oil and petroleum products themselves are serious environmental pollutants. Researchers have studied ways to reduce pollution from oily waste, to remove the oil film from water surfaces, and to utilize hazardous waste to reduce the negative impact of oil and oil products [50]. On carbon measurement supersites, some studies have explored the absorptive properties of ecosystems that can be used to reduce pollution. The use of plant material to clean up the environment has also been analyzed [51,52].

2.7 Ecosystem

This topic includes 16 articles published since 2022. One of the most important tasks of carbon polygons is to study the role of ecosystems in the balance of greenhouse gases, which is a subject that remains underexplored [53]. The territory of Russia includes several natural and climatic zones, with territories that differ greatly in their natural characteristics. Carbon measurement supersites represent a network through which various ecosystems are studied, for example, to elucidate the role of marshes in the carbon cycle or to reduce greenhouse gas emissions from peatlands [54]. At another supersite rare plants were studied to assess their role in ecosystem and carbon balances [55]. In addition, studies have focused on how ecosystems adapt to climate change and how forests maintain their sequestration capacity and dangerous boundaries beyond which they become carbon dioxide emitters [56].

2.8 Monitoring methods

The topic includes 15 articles published between 2017 and 2024 on methods of observing the balance of greenhouse gases. These articles are clearly divided into two categories: the first category focuses on measuring emissions, balance, and gas exchange at supersites; the second category monitors climate-active gases using remote sensing data. The first category considers various methods, including analysis of nighttime impurity accumulation in calm conditions [57], measurement of CO_2 flux between a forest ecosystem and the atmosphere [58], measurement of dissolved greenhouse gas concentrations in water using chromatographic methods with

head cameras [59], ground control using mobile laboratories equipped with lidar [60], and other methods. A significant part of the articles provided data on specific measurements taken in specific seasons and weather conditions [61]. In the second category of articles, researchers considered the use of satellite data to solve scientific and practical problems in greenhouse gas monitoring. For example, satellite methods enable the investigation of spatial and temporal variations of carbon dioxide in territories with significant diversity of anthropogenic sources. Thus, in Moscow's metropolitan area, using the nadir instrument onboard the OSO-2 satellite which measures solar radiation in the near–IR region of the spectrum, has revealed significant spatial and temporal fluctuations in carbon dioxide levels [62].

Mathematical modeling is often used to analyze the results of ground–based and remote sensing studies. For example, researchers have developed a three–dimensional hydrodynamic model that assesses the turbulent exchange coefficient for greenhouse gases and the wind speed field. The results of this assessment are combined with data on greenhouse gas concentrations at two levels above the surface, allowing for the assessment of greenhouse gas flows over significant relief dissections and a heterogeneous underlying surface [63]. Broader studies also relate to this topic. Researchers from 13 scientific centers across the Russian Federation their findings through a regional network of stations, included in RuFlux, an all–Russia system for monitoring ecosystem fluxes of greenhouse gases. At present, this network has accumulated substantial observational data on greenhouse gas flows. Most of the stations are geographically confined to the subzones of the middle and southern taiga. Notably, 86% of these stations are located in forest and marsh ecosystems. The authors draw general conclusions regarding the geographical patterns of CO_2 balance and emphasize the need to enhance the representativeness of the results to research all natural systems in Russia [64].

2.9 Carbon dioxide in the atmosphere

The topic includes 12 publications from 2021 to 2024 that consider various issues for reducing emissions of greenhouse gases and pollutants into the atmosphere. The issues explored by researchers range from public policy and legislative regulation to technical regulations in individual industries and the formation of a green economy in the Russian Federation. Review articles have examined the features of carbon unit exchanges, analyzing the principles of application of carbon quotas and green loans in the world and in Russia [65], as well as the main measures taken to reduce emissions in various sectors of the economy, regions, and countries [66]. At the regional level, attention has been paid to carbon emissions monitoring, which is combined with carbon landfill use and carbon absorption experiments conducted on farms [67]. Individual industries have been implementing various methods of control and regulation. Firstly, a quantitative assessment of the contribution of individual industries to individual branches of ferrous metallurgy was proposed by introducing a greenhouse number to characterize greenhouse gas emissions [68]. Secondly, methods for calculating mass and specific emissions of carbon dioxide per ton of natural and conventional fuel for boiler units of thermal power plants were considered [69]. Thirdly, an energy saving program was presented as a tool to reduce greenhouse gas emissions at mechanized production wells and ground infrastructure facilities of oil fields [70]. Additionally, researchers have studied patterns and factors that influence changes in concentrations of carbon dioxide (CO_2) and methane (CH_4) in surface atmospheres of urbanized and suburban areas [71].

2.10 Carbon dioxide in the water

The topic includes 9 publications from 2017 to 2024 related to assessing changes in the geochemical state of watercourses and reservoirs. Geochemical features and the ecological state of water bodies indicate the degree of anthropogenic transformation of natural environment components. Authors primarily focuse on toxicological monitoring based on microbiological studies results. For example, water quality in the Gulf of Finland resort site in 2020–2022 was classified as moderately polluted [72], while eutrophication coefficients were determined in surface waters near the city of Sterlitamak [73]. Water bodies within carbon measurement supersites and their surroundings were also the subject of hydrochemical and toxicological studies. For example, the study was conducted on Lake Kuchak (Tyumen Region) [74] and in the water zone of the Saralinsky section of the Carbon–Volga Region supersites at the Kuibyshev reservoir [75].

2.11 Supersites

The publications on this topic include 8 articles from 2022 to 2024, and they look like reports from supersites working in different locations across the country. The authors emphasize that carbon measurement supersites represent a set of scientific and technological solutions designed to establish a reliable framework for accounting greenhouse gas sequestration and emissions, as well as collecting an array of experimental data for developing a methodology to assess carbon balances in natural ecosystems [76]. Studies have identified the specific characteristics of specific supersites shaped by a combination of unique natural, social and technological

conditions. Attention is given to organizations working at these sites and the issues related to the regions where they are located [77]. Some researchers elaborate on the specific research conducted at each supersite outlining the potential for applying these findings to regional development [78]. The researchers also categorize the different types of carbon measurement supersites, their goals, and the results of supersites already in operation.

2.12 Collaboration

The topic contains 7 articles published between 2021 and 2022, which describe different forms of cooperation within supersites as well as with external actors. The researchers capture the role played by carbon measurement supersites in the development of regional institutions [79]. These supersites function as innovative institutions that complete the regional institutional framework by cooperating with economic, political, legal, and educational institutions. Carbon measurement supersites participate in regional projects, and their tasks are linked to other regional practices in education, leadership development and the creation of consultative councils for decision–making and building interaction between government branches in the region [80]. Some authors also emphasized that studies on carbon supersites align with global trends that connect global issues with regional institutions' work [81].

2.13 Nature-based solution project

This topic contains 7 publications from 2021 to 2024 that address various nature–based solutions projects in the Russian Federation, particularly in the context of the challenges of the green economy and sustainable development. Some authors presented successful examples of green investments in the modernization of industrial enterprises, pointed out industries that face difficulty implementing green economic principles [82]. Carbon supersites could contribute to developing and testing low–carbon technologies, greenhouse gas capture and utilization technologies, and second-energy projects. Other authors criticized the lack of nature–based projects in forestry and proposed key green economy principles for transitioning to sustainable development in this sector [83]. Another direction for creating carbon–neutral projects was to develop green infrastructure in cities based on green spaces and explore its role in achieving carbon neutrality [84].

2.14 Land use type

The topic includes 7 publications from 2021 to 2024 concerning the regulation of greenhouse gas emissions in forestry and agriculture. The authors studied ways to improve legislative regulation and forestry activities as an aspect of adapting the forest complex to climate change [85], and analyzed the priority determinants for increasing the efficiency of forest wood resource use [86] and the relevance of information used to calculate estimated cutting territories [87]. Another focus was on problems with forest transformation in rural locations, changes in forest land fields and shortcomings in the territorial organization of forests [88]. Relevant issues include the volumes of carbon absorbed by different forest types, as well as greenhouse gas emissions from forest fires, and the conversion of forest lands into other categories leading to deforestation.

Forecasting and modeling of greenhouse gas emissions in agriculture remained the main research area [89]. To improve the accuracy of calculations and forecasts, researchers considered the possibility of using mathematical modeling to calculate greenhouse gases emissions from crop production, taking into account different natural and climatic conditions, soil types, and types of crops [90]. In general, researchers focused on automation of agricultural management. Studies also addressed the issue of drained peatlands, which emit greenhouse gases [91]. They explored an approach to reducing greenhouse gas emissions through secondary irrigation based on the assessment of effectively flooded fields that could be considered wetlands.

Significant fields of land have lost their original natural functions, so modeling the carbon balance on disturbed lands has been a priority for researchers. Therefore, calculations of emissions at solid municipal waste landfills showed that their contribution can reach 1.6% of the total mass of greenhouse gas emissions in CO2 equivalent [92].

2.15 ESG project

This topic includes 7 publications connecting the topic of carbon measurement supersites with ESG projects. Carbon measurement supersites could become a scientific foundation for companies to implement ESG principles through responsible investments in innovative projects that lead to a reduced carbon footprint and a circular economy, as well as a transition to alternative materials and renewable energy sources [93]. However, researchers have expressed concerns that rapid decarbonization of the economy could lead to serious economic crises, suggesting that predicting the effects of decisions should be done through carbon measurement supersite

analysis. In addition, these supersites could contribute to the design and planning of natural solutions, emphasizing benefits for all parties involved, making such projects attractive as part of ESG investments [94].

Thus, due to the topic modeling conducted, we identified the main areas of research, which are divided into two clusters. The first cluster relates to climate policy, discussing threats and opportunities for the Russian Federation, as well as issues related to sustainable development and ESG strategies. The second cluster relates to scientific research itself, including measurements, methods, data, etc. Most widely represented topics include climate policy and studies on the carbon balance in soil cover under various landscape and geochemical conditions. A substantial number of studies explore the dependence of ecosystem carbon balance on landscape functioning, assessment of carbon balance in human–transformed systems, study of carbon cycles, and causes of greenhouse gas emissions and accumulation. There is almost no mention of international cooperation, although developing such cooperation is one of the goals of carbon measurement supersites.

It should be noted that Russia has very serious internal reasons for solving scientific issues related to monitoring greenhouse gas emissions and climate change, as well as developing adaptation and mitigation ways. Firstly, two thirds of the territory of Russia is occupied by northern territories, which are most vulnerable to the negative consequences of climate change and remain under-researched. Secondly, different regions of Russia have different natural conditions and socio–economic situations, which makes it difficult to develop standard adaptation measures and maximizes the role of local conditions in decision making. However, as researchers note, carbon measurement supersite network has begun to be developed in response to external challenges rather than internal needs. The main challenges were the prospect of introducing a carbon tax and the need to prove the high potential for sequestration of Russian ecosystems. This motivation has seriously influenced the specific areas of research on supersites. The goals of carbon measurement supersite are to establish a robust system for accurate recording of greenhouse gas absorption and emissions, as well to gather a range of experimental data to refine methods for assessing the carbon balance in natural ecosystems.

Much less research on carbon measurement supersites aims to solve local economic and social problems and reduce emissions to mitigate the anthropogenic impact on the climate. Firstly, topic modeling has revealed a limited number of publications discussing the effects of research into carbon supersites on regional economies. Secondly, only a few articles published in the short period between 2021 and 2022 focused on stakeholder interactions around the activities of research centers. Thirdly, the considered topics include an insignificant number of papers that described nature–based solutions for specific territories. Finally, the smallest number of articles describe the contribution of carbon measurement supersites to the implementation of ESG strategies by individual companies.

Conclusion

To identify key research areas related to the topic of carbon measurement supersites we used topic modeling to analyze texts of articles in the largest Russian digital libraries on carbon–related topics. As a result of topic modeling, 15 significant topics were identified in the text collection. We assessed the dynamics of each topic from 2014 to 2024 and the number of publications related to that topic. Then, provided detailed descriptions of the content for each identified topic.

The study concluded that carbon measurement supersites were created to strengthen the position of the Russian Federation in international trade, in connection with the transition to carbon regulation and introduction of carbon taxes. Researchers paid less attention to solving internal problems related to adaptation of territories to climate change and reducing anthropogenic impact on climate. We propose expanding the participation of carbon measurement supersites in addressing regional issues:

1. Based on scientific results, scientists can propose natural and climatic solutions aimed at adapting to climate change and reducing climate risks. Each solution should be assessed in terms of the resulting social and economic effects and the possibility of scaling up to other territories.
2. Carbon measurement supersites can develop and implement technologies for key sectors of the regional economy, which will then be offered to companies. Small and medium–sized businesses cannot independently bear the costs of R&D to create such technologies; therefore, collaboration with scientists can facilitate the implementation of low–carbon technologies at such enterprises.
3. Carbon measurement supersites can serve as a foundation for Advisory Councils that bring together scientists, government officials, businesspeople, representatives of public organizations and activists to discuss the transition of regions to low–carbon development and the adoption of strategic goals. Scientists can consult on specific issues or formulate research proposals for businesses, governments and the public within the framework of these Advisory Councils.

4. Federal and regional authorities can utilize carbon measurement supersites to implement measures to support research aimed at solving the most important regional problems and defining strategic priorities for low–carbon development, as well as create conditions for stakeholder interaction.

Thus, we have identified the main directions for future research on carbon measurement supersites, which could contribute to implementing climate policies related to adapting individual territories and industries to climate change and reducing anthropogenic impact on the climate.

The limitations of the study are due to the fact that our topic modeling was restricted to articles published in Russian, while there are publications of research results on carbon measurement supersites in English that that could have contributed to or altered the results of our analysis.

Acknowledgements

This study was supported by the Ministry of Science and Higher Education of the Russian Federation within the framework of the Carbon Measurement Test Area in Tyumen' Region (FEWZ–2024–0016).

We are grateful to Valeria Evdash and Nadezhda Zhuravleva (Center for Academic Writing "Impulse", University of Tyumen) for their assistance with the English language.

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КАРБОНОВЫЕ ПОЛИГОНЫ В РОССИИ: ИСПОЛЬЗОВАНИЕ ИНФОРМАЦИОННЫХ ТЕХНОЛОГИЙ ДЛЯ ВЫЯВЛЕНИЯ ИССЛЕДОВАТЕЛЬСКИХ ТРЕНДОВ (2014–2024)

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Аннотация

Понимание динамики парниковых газов помогает оценивать количество выбросов, разрабатывать стратегии мониторинга, совершенствовать управление земельными ресурсами и стремиться к углеродной нейтральности. Для поддержки исследований по всему миру созданы карбоновые полигоны. В России проект по созданию карбоновых полигонов был запущен в 2021 году. Данная работа определяет тренды в области исследований, связанных с карбоновыми полигонами, с помощью тематического моделирования анализа статей из крупнейших российских цифровых библиотек. Выделено 15 значимых тем, проанализирована их динамика с 2014 по 2024 год. Эксперты подробно описали каждую тему, подчеркнув роль карбоновых полигонов в укреплении позиций России в углеродном регулировании и торговле. Рекомендуется расширение их регионального влияния.

Ключевые слова

карбоновые полигоны; тематическое моделирование; углеродная тематика; углеродное регулирование; парниковые газы

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