ORIGINAL ARTICLE

DOI: https://doi.org/10.18599/grs.2021.3.2 Russian Original 2021. Vol. 23. Is. 3. Pp. 8–16

Some challenges and opportunities for Russia and regions in terms of the global decarbonization trend

D.K. Nurgaliev, S.Yu. Selivanovskaya, M.V. Kozhevnikova, P.Yu. Galitskaya*
Kazan Federal University, Kazan, Russian Federation

Abstract. This article discusses a possible scenario of energy transition in Russia, taking into account the economic structure, presence of huge oil and gas infrastructure and unique natural resources. All this allows to consider global trends of energy and economic decarbonization not only as a challenge, but also as a new opportunity for the country. Considering developed oil and gas production, transportation, refining and petrochemical infrastructure, as well as the vast territory, forest, water and soil resources, our country has unique opportunities for carbon sequestration using both biological systems and the existing oil and gas infrastructure. It is proposed to use the existing oil and gas production facilities for hydrogen generation in the processes of hydrocarbon catalytic transformation inside the reservoir. It is suggested to create and use large-scale technologies for CO_2 sequestration using existing oil and gas production infrastructure. Considering high potential of the Russian Federation for carbon sequestration by biological systems, a network of Russian carbon testing areas is being developed, including one at Kazan Federal University (KFU), – the "Carbon-Povolzhye" testing area. The creation of carbon farms based on the applications at such testing areas could become a high-demand high-tech business. A detailed description of the KFU carbon testing area and its planned objectives are given.

Keywords: energy transition, decarbonization, hydrogen generation, CO_2 disposal, carbon sequestration by biological systems, carbon testing area

Recommended citation: Nurgaliev D.K., Selivanovskaya S.Yu., Kozhevnikova M.V., Galitskaya P.Yu. (2021). Some challenges and opportunities for Russia and regions in terms of the global decarbonization trend. *Georesursy = Georesources*, 23(3), pp. 8–16. DOI: https://doi.org/10.18599/grs.2021.3.2

Introduction

A complete rejection of fossil fuels, including hydrocarbons (HC) as an energy source, is unlikely in the coming decades, but there is no doubt that the trend towards decarbonization will continue, and the economic structures of countries will change. Today, the scientific world recognizes that the burning of carbon fuels is the main cause of the accumulation of greenhouse gases in the atmosphere, and this leads to an increase in the average temperature of the planet. The consequences of this process are already being found in the strong variability of weather conditions, the more frequent observation of catastrophic events and a noticeable warming in the Arctic zone. All this is due to the violation of natural cause-and-effect relationships in the "atmosphere-ocean-climate" system. Subsequent melting of the methane-containing permafrost and rising ocean levels could lead to extremely negative consequences, and it is likely that these changes can no longer be stopped. By the end of the century, the average temperature may rise by more than 2.7 °C, although it is planned (according to the Paris Agreement) to keep its growth at 1.7 °C, or at least no more than 2.0 °C. As one of the major measures, it is planned to introduce a cross-border carbon tax in the EU, and the funds received will be used to develop green energy and compensate for the consequences of "global warming". This is, in fact, a unique event in the history of civilization, when global strategic thinking aimed at the self-preservation of mankind materializes and is transferred to the economic plane not only within the framework of a separate state, but also at the interstate level. This is the first step in this direction, but the economic instrument is initiated by the EU, not a global body, and how effective it will be for solving the tasks set in the Paris Agreement is not yet clear, time will tell. Nevertheless, since we are already emitting greenhouse gases on a scale that can change our entire planet, and not only initiate some kind of regional environmental problems, humanity will have to begin to regulate the elements of this complex system.

*Corresponding author: Svetlana Yu. Selivanovskaya
e-mail: svetlana.selivanovskaya@kpfu.ru

Unfortunately, most states and politicians today do not fully assess the significance of the current situation. It would probably be easier to unite in understanding and taking action against the asteroid hazard. Climate change, caused, in fact, by the burning of fossil fuels, is a special problem that affects many aspects of society – the provision of energy, electricity, as well as the revenues of many countries that extract these fossil fuels, and the costs of many states that do not have these natural resources, the problems of states that have nothing to do with fossil fuels – they do not produce them and do not use them. The interests of various states, international corporations are intertwined in a complex way in this problem. The preamble to the Paris Agreement notes that "Parties may suffer not only from climate change, but also from the impact of measures taken to respond to it".

It is necessary to discuss the problem, solve it taking into account the nuances and problems of all participants in the process. We are talking about a new paradigm in global thinking, when one of the most important factors in making decisions about the further development of states is the awareness of global threats such as global warming.

A very simple example is from the field of economics. If earlier in the optimization calculations of the cost of a product, the objective function had the dimension of cost, which included various direct and indirect costs, including environmental ones, today it is also a carbon footprint expressed in tons of CO_2 (and today already in euros) allocated to all stages of product production. Moreover, the damage can manifest itself in a completely different place, not at all where the product was produced. This new factor is changing the entire economy, which means politics and all aspects of human activity: health, education, safety, food production, clothing, housing, minimal surrounding infrastructure, etc.

We live in an era when a new period begins in the history of the planet – the influence of one of the biological species begins to disrupt the complex nonlinear system of Gaea (Kleidon, 2004), and in order to take corrective action, humanity will be forced to take control of the processes in the oceans, subsurface, forests, tundra and other natural objects – all components of this system. Geologists and stratigraphers call this period the Anthropogene (Carpejani et al., 2020), although it looks more like some prominent boundaries between geological systems, characterized by unique global events – mass extinctions of biological species due to a variety of reasons. The mass extinction in the biosphere today is one of the most significant in the history of the Earth, and it proceeds extremely rapidly on a geological time scale. How can Russia be in this situation, what to do?

Russian energy transition: balance of natural resources and global trends

On the face of it, the confidence and decisiveness with which the EU and many other countries talk about a green energy transition does not bode well for Russia, which today provides almost 40% of its budget from oil revenues. Many Russian exported goods with a large "carbon footprint" (steel, aluminum, gas, oil and oil products, agricultural products, etc.) will be burdened with a carbon border adjustment mechanism (CBAM), and this will not contribute to their competitiveness in the market. Nevertheless, it can be argued that this challenge for the Russian economy is at the same time a huge opportunity.

The "green" energy transition should take place in Russia, taking into account the rational use of available natural resources – hydrocarbon, biological and territorial, as well as the created oil and gas infrastructure – specific wells, explored reservoirs, hydrocarbon deposits, all ground infrastructure, including pipelines, as well as oil refining and petrochemical power. The strategic goal for the next 30–40 years is to provide the country with hydrocarbon reserves that are competitive in the world market, which must be produced environmentally, economically, and with a low carbon footprint.

Russia's next step towards a green economy is the transition to the production of hydrogen, a new energy agent. For this, it is necessary to create industrial technologies for generating hydrogen directly in oil and gas deposits and burying the resulting CO_2 in natural reservoirs. In this direction, work is underway in several laboratories in the world. Kazan Federal University (KFU) has a successful experience of using catalysts to improve the efficiency of thermal methods for the production of super-viscous oil (Vakhin et al., 2020; Varfolomeev et al., 2021). in situ combustion technologies. Russian and foreign (Kuwait, Oman, China) oil and gas companies are showing great interest in these technologies.

Another step towards green energy is the creation and implementation of industrial carbon sequestration technologies using available natural resources and oil and gas infrastructure. The presence of a vast territory, forest, water, soil resources opens up unique opportunities for our country to sequester carbon using biological systems. In addition, using existing and already developed hydrocarbon fields, using the experience of monitoring gas storage facilities, it is necessary to implement the sequestration of greenhouse gases formed during hydrogen generation, as well as in other processes, in natural reservoirs.

The implementation of these proposals will allow the Russian Federation not only to reach the level of carbon neutrality, but also to sell significant volumes of carbon credits and organically integrate into the global "green" economy. All these proposals and expected results correlate with the National Goals and the Strategy for the Scientific and Technological Development of the country, both in terms of providing the country with green energy and creating new "green" businesses and high-tech jobs in the field of carbon sequestration by ecosystems.

For the regions, in particular the Republic of Tatarstan, the implementation of such a program will lead to the restructuring of the oil and gas production, energy and agricultural sectors of the region, attracting investments for these purposes, and ensuring leadership in the field of generation, storage and transportation of hydrogen. Those the republic can come to carbon neutrality, including through the large-scale introduction of technologies for sequestration of carbon by ecosystems and using the oil and gas production infrastructure.

Possibilities of biological sequestration of carbon dioxide and the creation of carbon testing areas. Opportunities and tasks of the "Carbon-Povolzhye" testing area

The immediate task in the implementation of the proposed plan on the way to a "green" economy is the creation of carbon testing areas, which are entrusted with the functions of assessing greenhouse gas fluxes, and the development of effective technologies for sequestration of carbon dioxide by a variety of natural biological systems.

The Russian Federation is the fifth country in the world in terms of greenhouse gas emissions, however, there is no developed system for their monitoring (Climate Analysis Indicators Tool – CAIT 2.0). At the same time, the countries of the European Union have already created an integrated system of carbon observing stations "Integrated Carbon Observation System – ICOS". The network of ICOS stations includes a number of measuring stations located in Belgium, Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, Great Britain. The stations monitor greenhouse gas fluxes either in the atmosphere (38 stations), or over the ocean (23 stations), or in entire ecosystems (86 stations). The observations are coordinated by the head office, and the Carbon Portal is responsible for the collection and dissemination of ICOS data and derived information products. In order to determine the potential of Russia's natural systems to sequester carbon, it is necessary to organize a comprehensive system for monitoring greenhouse gases, to create a system for assessing the carbon balance of natural systems in different climatic and geographical zones. For this purpose, by order of the Ministry of Science and Higher Education of the Russian Federation No. 74 of February 5, 2021 "On testing areas for the development and testing of technologies for monitoring carbon balance", a system of "Carbon testing area" is being created. The creation of such a system is the implementation of the first stage of the national action plan for adaptation to climate change for the period up to 2022.

One of the participants in the program is Kazan Federal University, which is creating the Carbon-Povolzhye carbon testing area. In the future, a carbon farm will also be created.

The carbon testing area is being organized as part of a consortium to create climate change models and methods for accounting for the emission and absorption of climatically active gases, and for determining the amount of carbon deposition by terrestrial ecosystems. An important part of the work will be the development of technologies for long-term carbon sequestration.

The carbon testing area is subdivided into two areas – a forest area and a water area. The forest area is located on the territory of the Observatory (Zelenodolsk district of the Republic of Tatarstan), which is the property of the KFU.

The main landscape type of this area is a hairy sedge lime wood with fir and oak on sod-podzolic soils, located on alluvial-deluvial Quaternary deposits of the third terrace of large rivers. The species composition of the community is represented by heart-shaped linden (bonitet II; maximum age – 106 years, average – 60; diameter – 35 cm, average height – 24 m), Finnish spruce (bonitet I; maximum age – 109 years, average – 80 years; diameter trunk – 66 cm, average height – 28 m), pedunculate oak (bonitet II; maximum age – 101 years, average – 80 years; diameter – 72 cm, average height – 24 m). The height of the shrub layer is 2 m. The shrub layer is sparse, herbaceous, the ground cover is continuous, up to 70 cm high, multi-tiered. In the undergrowth there is warty euonymus, common honeysuckle, plane maple, hazel.

The soils of this area are sod-podzolic on alluvial-diluvial deposits with horizons A0 (0–3 cm), A1 (3–7 cm), A1A2 (7–15 cm), A2 (15–37 cm), B (37–70 cm), CD (70–100 cm). The soils are weakly acidic (pH aq – 6.3, pH salt – 5.6), fairly well humous (humus – 3.0%, N – 0.18%, C/N – 9.66).

According to the amount of precipitation, the area in which the forest area of the carbon testing area is located belongs to the zone of moderate moisture, their annual amount is 552.5 mm. The greatest amount of precipitation occurs in July (66.3 mm), and the least in March (23 mm). The number of days with snow cover is 156 days. A stable snow cover forms in early November and disappears in mid-April. The height of the snow cover reaches its highest values in March – an average of 56 cm.

Soil freezing in winter is maximum 69 cm. The total solar radiation in this area is about 3900 MJ/m^2 per year, the radiation balance is 1311 MJ/m^2, and from November to February it is negative. The sunniest period is from April to August.

With regard to the water section of the testing area, discussions are currently underway on its best location.

Carbon-Povolzhye testing area is designed to solve the following tasks: a) creation of a system for collecting, validating and processing data, allowing them to be integrated into the general model of sources and effluents in the region and the Russian Federation; b) organization of regular meteorological observations; c) organization of regular remote monitoring (including satellite data) of climatic active gases; d) organization of regular monitoring observations of the flows of the main greenhouse gases and the parameters of photosynthesis and respiration of plant communities and soil.

The carbon testing area will become a center for collection, validation and processing of data and will allow integrating them into a general model of sources and sinks of greenhouse gases in the region and the Russian Federation. Such a system will be the basis for constructing quantitative estimates of the emission and deposition of greenhouse gases (CO_2, CH_4, N_2O) in the natural and transformed landscapes of the Republic of Tatarstan.

Other directions of activity of the carbon testing area are the assessment of the sequestration potential of natural phytocenoses and individual groups of plants with the identification of the most productive communities and individual plant species, as well as the adaptation of plants with high sequestration potential, not characteristic of local flora, to the climatic conditions of the region and the development of technology for their use in agriculture and forestry.

An important result of the activities of the carbon testing area should be the creation of a certification center for specialists in the validation and verification of greenhouse gas accounting and compensatory measures.

Undoubtedly, the educational and educational function of the testing area, which consists in adapting existing and developing new bachelor's, master's and postgraduate programs, organizing seminars and conferences held on the basis of the carbon testing area.

Research and development of the carbon testing area is based on the accumulated Russian and international experience. So, on the territory of Russia in 1978, observations were started at the Central Field Experimental Base of the FGBI "MGO" in Voeikovo (Alferov et al., 2017). Later, stations were created on the island. Bering, about Kotelny, Teriberka, Novy Port and Tiksi. Currently, the Novy Port and Voeikovo stations, located near large-scale pollution sources, are used to study the variability of greenhouse gas emissions (Zinchenko et al., 2001; Zinchenko et al., 2002; Makarova et al., 2006; Zinchenko et al., 2008; Reshetnikov et al., 2009).

Since the beginning of the 2010s, intensive studies of greenhouse gas fluxes have begun by the method of microdynamic pulsations and closed chambers in Valdai and in the Leningrad region (Karelin et al., 2020; Safonov et al., 2012; Yuzbekov et al., 2014; Alferov et al. ., 2017). Currently, much attention is paid to the assessment of greenhouse gas emissions in the Arctic zones. Thus, in the paper (Tei et al., 2021), the results of seasonal measurements of greenhouse gas emissions under permafrost conditions are presented. This study examines the exchange fluxes of carbon dioxide (CO_2) in the border ecosystems of the taiga and tundra in northeastern Siberia from 2013 to 2015. During the growing season (May–September), CO_2 uptake was observed in volumes of –39.4 (from –60.1 to –20.2) gC/m^2. It is shown that the microclimatic factors that determine the exchange fluxes of CO_2 change seasonally. They are significantly influenced by the time of the onset of carbon uptake, associated primarily with the soil temperature in spring and early summer, after which the determining factor becomes the flux density of photosynthetic photons. In the paper (Holl et al., 2019) long-term time series of carbon dioxide fluxes in the Siberian Arctic were presented, measured by the eddy covariance method. The same method was applied to estimate the volumes of net primary production and energy fluxes in the bogs of Western Siberia (Alekseychik et al., 2017). Based on measurements in May–August 2015, the first estimates of the carbon dioxide balance in a typical middle taiga swamp are presented. The areas where the carbon dioxide flux measurements were carried out consisted of an alternation of wooded uplands and depressions occupied by sedges and shrubs. During all four months of measurements, the CO_2 uptake was comparatively high at 202 gC/m^2. In contrast, CO_2 emissions were observed during several transition periods in June and July.

The work of the Institute of Biology of the Komi Scientific Centre of the Ural Branch of the Russian Academy of Sciences is devoted to the ecosystem exchange of carbon dioxide and water in various types of ecosystems. For the spruce forests of the European North-East of Russia, a well-pronounced daily variation of CO_2 gas exchange from March to October with a maximum at noon was demonstrated. In the winter months, the values of the net CO_2 exchange were positive. The total daily value of the net carbon dioxide exchange per day was in April 4, May – 62, June – 79, August and September – 31% of the July value. The total net CO_2 absorption by the spruce forest in April – August corresponded to –327 gC/m^2. For pine forests of the same region, a correlation was found between the daily average values of gross photosynthesis and total evaporation. The total net CO_2 exchange, gross photosynthesis, and ecosystem respiration in the pine forest were estimated at –103, –407, and 304 gC/m^2 year, respectively (Zagirova et al., 2020).

As mentioned above, the respiration of ecosystems, which consists of the plant and soil components, makes a significant contribution to the carbon cycle (Houghton et al., 1992). Soil is one of the most important natural reservoirs of carbon, and the exchange of carbon between the soil and the atmosphere is very active. Thus, the emission of this gas from the soil is the second most important component of the global carbon cycle and, accordingly, climatic changes (Reth et al., 2005; Lal et al., 2018; Bernoux et al., 2005). It is no coincidence that one of the global initiatives aimed at reducing the carbon dioxide content in the atmosphere is the "4 permille" initiative, which assumes an annual increase in sequestered organic carbon in soil by 4 ‰ in a layer of 30–40 cm, due to a change in agricultural practices (Chabbi et al., 2017; Corbeels et al., 2019; de Vries, 2018; Lal, 2016; VandenBygaart, 2018).

The carbon balance in the system "soil-subsurface layer of the atmosphere" is formed by the processes of its emission (as a result of mineralization of soil and organic matter introduced by plants and fertilizers) and its accumulation (as a result of the accumulation of plant waste and other dead organic matter, root exudates, as well as the introduction of organic carbon with fertilizers).

Mineralization of organic matter is carried out by soil microorganisms and depends both on the amount and composition of the former and on the activity of the latter. Traditionally, soil organic carbon content is estimated during agrochemical surveys and, together with an indicator of carbon content in microbial biomass, indicates the degree of soil fertility. Organic carbon makes up about 55–60% of the mass of soil organic matter (Canedoli et al., 2020). It has been shown that the content of organic carbon in the soil significantly depends on its type; for agricultural soils of a temperate climate, it can fluctuate within 5–30 g/kg of the fertile layer, 0.5–4.5% of which are contained in the microbial biomass. In general, the reserves of organic carbon in these climatic conditions are 15–80 t/ha in the 0–20 cm layer and 5–20 t/ha in the 20–40 cm layer (Xie et al., 2021; Shukla et al., 2005). Another factor affecting the rate of soil organic carbon mineralization is the climatic conditions in which it is located (Alvarez et al., 2001; La Scala et al., 2006). In general, soil carbon stocks are more susceptible to different types of influences in warm and humid conditions than in cool (but not frosty) and arid conditions (Ogle et al., 2019).

The type of land use and the method of soil cultivation in agriculture affects the intensity of organic carbon mineralization in it (Reicosky, 2001). The intensification of the decomposition of soil organic matter during tillage occurs due to the destruction of soil macroaggregates and the release of carbon "packed" in it, available to microorganisms. In addition, plowing contributes to a better supply of oxygen to the soil, which also leads to the intensification of mineralization processes (Cambardella et al., 1992). It has been shown that the amount of soil carbon lost in the form of carbon dioxide correlates with the intensity of destruction of aggregates and the volume of displaced soil (Reicosky et al., 2007; La Scala et al., 2006). For example, the amount of carbon dioxide emitted from the soil under corn crops was 0.82, 0.56, 0.51, and 0.49 $g{\cdot}m^{-2}{\cdot}h^{-1}$ under the following treatment options: standard moldboard, reduced till, minimal tillage, and no moldboard tillage (McNunn et al., 2020). Replacement of a dump type of tillage with a non-dump type within 20 years leads to an annual increase in soil organic carbon stocks by 0.06–0.35, 0.21–0.50 and 0.34–0.54 t/ha under conditions cold, warm and tropical climates, respectively. Interestingly, this tendency is typical only for the upper fertile soil layer (about 20–25 cm) (Ogle et al., 2019). In the lower soil layers, on the contrary, non-moldboard tillage leads to a decrease in the organic carbon content (Angers et al., 1997).

Recently, researchers are increasingly talking about the significant potential of the underlying soil layers for carbon sequestration, and for the exchange of carbon between the soil and the atmosphere in general (VandenBygaart et al., 2011). There is currently not enough information to draw full conclusions about the role of the underlying soil layers in the accumulation of carbon, as well as the effect of various practices on its turnover in the soil and between the soil and the atmosphere. Thus, the longest series of observations of the content of organic carbon in the soil with the abandonment of moldboard cultivation is 45 years, while most of the observation series does not exceed 20 years. The set of measured parameters in these observations is different. At the same time, stabilization of the sorption of organic compounds produced by microorganisms after their migration into the underlying soil layers may require a longer study period (Cotrufo et al., 2013;

Lehmann et al., 2015). It was found that treatment has a greater effect on the carbon content in the soil at a depth of 60 cm in clay, silty and silty soils in tropical and subtropical climatic conditions compared to sandy soils in the same climatic conditions. At the same time, in temperate latitudes, this tendency is reversed: it is sandy soils that are most susceptible to the influence of moldboard plowing in terms of their carbon content, incl. at depths exceeding the plow penetration depth (Ogle et al., 2019). In some cases, not only the amount of carbon dioxide is determined, but also of other greenhouse gases, expressing the total emission in the mass of the so-called. CO_2 equivalent. But even in this case, the described tendency of an increase in volumes with an increase in the degree of impact on the soil is traced. So, the emission from the soil under fallow was 520, 400 and –230 kg eq-CO_2 ha^{-1} $year^{-1}$, and from the soil under clover – 100, –50, –1900 kg eq-CO_2 ha^{-1} $year^{-1}$ for the standard, truncated and non-moldboard plowing, respectively (a negative value corresponds to the absorption, not the release of carbon dioxide) (McNunn et al., 2020).

Fertilization has an interesting effect on the rate of mineralization of soil organic matter. Mineral fertilizers increase microbial activity in general due to the introduction of limiting macro- and microelements and, thus, intensify the processes of microbial decomposition of organic carbon in the soil. On the other hand, mineral fertilizers lead to plant growth and development, intensification of root exudation, accumulation of plant litter, i.e. to sequestration of carbon in the soil. The shift in the balance between these two processes towards the accumulation of carbon in the soil is the subject of a large number of scientific studies. Organic fertilizers, such as composts from manure, sewage sludge and other organic waste, contain significant amounts of organic carbon and short-term increase in soil reserves after application. However, in most cases, carbon in such fertilizers is contained in a form readily available to microorganisms, therefore, it quickly mineralizes and does not accumulate in the soil in the long term. Moreover, with the introduction of readily available organic substances in the soil, the so-called priming effect, consisting in the intensification of the mineralizing activity of the soil microflora not only in relation to the introduced, but also in relation to the previously existing organic matter in the soil. As a result, the application of organic fertilizers not only does not contribute to an increase in soil carbon stocks, but also vice versa – leads to their decrease. Biochar, a product of anoxic thermal decomposition of biomass, can become an alternative to these rapidly decomposing organic fertilizers. It not only contributes to the intensification of plant growth, but also, being a slowly decomposing fertilizer, allows long-term preservation of carbon in the soil.

Thus, to reduce carbon dioxide emissions in agriculture, a decrease in the intensity of soil cultivation, elimination of grazing, sowing ground cover plants, competent management of crop rotation and improvement of fertilization practices can be used (Eze et al., 2018; Olson et al., 2010; Parkin et al., 2016; Snyder, 2017) In general, it is estimated that measures to reduce the volume of soil organic carbon losses can be implemented on agricultural areas of up to 57 million hectares. The introduction of such measures can lead to significantly higher volumes of carbon sequestration than the 4 ‰ declared in the corresponding initiative. Thus, the annual sequestration of carbon in the 0–30 cm layer in the volume of 2–3 t/ha was achieved by changing the type of soil use, which was characterized by initial carbon stocks of 19 t/ha. This was not 4 ‰, but 70–189 ‰ per year (Noulèkoun et al., 2021).

If soil is not included in agricultural use, erosion and accumulation, as well as the nature of the vegetation cover, become the main factors affecting the accumulation of organic carbon and the release of carbon dioxide. In eroded areas, where a significant amount of mineral particles come to the surface, there is a tendency to accumulate organic carbon due to its sorption on these particles. In accumulative areas, the accumulation of organic carbon in the soil is also observed due to the burial of the reclaimed fertile layer under the mineral layer, and the associated decrease in the rate of mineralization of the buried organic matter. In general, researchers estimate the volume of global carbon accumulation in soil as a result of anthropogenically induced erosion processes at 78 billion tons for terrestrial ecosystems (Shukla et al., 2005; Wang et al., 2017).

Plants can both absorb and emit carbon dioxide during the day. During periods of active development and growth of biomass, this balance is shifted towards the absorption and sequestration of CO_2 in the biomass. Up to 89% of the carbon sequestered by plants is then transferred to the soil (Eze et al., 2018). The introduction of carbon occurs due to carbonaceous root exudates, which are hardly biodegradable, as well as due to the accumulation of dead plant parts in the soil (Noulèkoun et al., 2021; Rasse et al., 2005). Woody vegetation is the best carbon dioxide absorbant compared to herbaceous vegetation (Chen et al., 2018; Chan et al., 2008; Poulton et al., 2018). However, the global role of herbaceous areas in carbon sequestration is extremely high – they account for about 40% of the land surface, they contain 34% of global soil carbon reserves (Eze et al., 2018). The amount of carbon accumulated in the soil can also differ between different herbaceous crops (McNunn et al., 2020).

In Russia, as a result of monitoring the agrochemical properties of soils, information has been accumulated on the content of organic matter in the upper soil layer. Much less data are available on the intensity of soil respiration, which is an indicator of the intensity of mineralization of organic matter, and soil microbial biomass in the upper soil layer. There is practically no information on carbon fluxes in the soil and the subsurface layer of the atmosphere, as well as on the carbon balance in individual ecosystems and regions, calculated using remote sensing data using models.

That is why the creation of carbon testing area designed to combine efforts to monitor greenhouse gases, to build models of their distribution, to create carbon sequestration technologies based on the fundamental laws of carbon balance in various ecosystems is an urgent and necessary task in Russia.

Conclusion

1. Global trends in the decarbonization of energy and the economy as a whole, aimed at reducing the consequences of global climate change, are not only a challenge for Russia, but also open up new opportunities.

2. A new approach to the Russian energy transition is proposed, taking into account the rational use of available natural resources – hydrocarbon, biological and territorial, as well as the created oil and gas infrastructure – specific wells, investigated reservoirs, hydrocarbon deposits, all onshore infrastructure, including pipelines, as well as oil refining and petrochemical productive facilities.

3. It is necessary to create and implement industrial technologies for generating hydrogen directly in oil and gas deposits and burying the resulting CO_2 in natural reservoirs.

4. It is necessary to create and implement industrial technologies for sequestration of carbon, both using biological systems and by injection and storage in natural reservoirs.

5. The immediate task in the implementation of the proposed plan on the way to a "green" economy is the creation of carbon testing areas, the main function of which will be the assessment of the flow of greenhouse gases and the development of efficient technologies for sequestration of carbon dioxide by natural biological systems.

6. Carbon testing area of the Republic of Tatarstan "Carbon-Povolzhye", which is operated by Kazan Federal University, will become a center for collection, validation and processing of data, which will be further integrated into the general model of greenhouse gas emissions and sinks in the region and the Russian Federation. Such a system will become the basis for constructing quantitative estimates of the emission and deposition of greenhouse gases (CO_2, CH_4, N_2O) in natural and transformed landscapes.

7. Despite the availability of data on agrochemical properties and the content of organic matter in the upper soil layer, in Russia there is practically no information on carbon fluxes in the soil and the subsurface layer of the atmosphere, as well as on the carbon balance in individual ecosystems. Obtaining such data is necessary for the subsequent creation of nature-like carbon sequestration technologies.

References

Alekseychik P., Mammarella I., Karpov D., Dengel S., Terentieva I., Sabrekov A., Lapshina E. (2017). Net ecosystem exchange and energy fluxes measured with the eddy covariance technique in a western Siberian bog. *Atmospheric Chemistry and Physics*, 17(15), pp. 9333–9345. https://doi.org/10.5194/acp-17-9333-2017

Alferov A., Blinov V., Gitarskii M., Grabar V., Zamolodchikov D., Zinchenko A. et al. (2017). Monitoring of greenhouse gas flows in natural ecosystems. Saratov, 279 p. (In Russ.)

Alvarez R., Alvarez C. R., Lorenzo G. (2001). Carbon dioxide fluxes following tillage from a mollisol in the Argentine Rolling Pampa. *European Journal of Soil Biology*, 37(3), pp. 161–166. https://doi.org/10.1016/S1164-5563(01)01085-8

Angers D.A., Bolinder M.A., Carter M.R., Gregorich E.G., Drury C.F., Liang B.C., et al. (1997). Impact of tillage practices on organic carbon and nitrogen storage in cool, humid soils of eastern Canada. *Soil and Tillage Research*, 41(3–4), pp. 191–201. https://doi.org/10.1016/S0167-1987(96)01100-2

Bernoux M., Cerri C. C., Volkoff B., Carvalho M. da C. S., Feller C., Cerri C. E. P., et al. (2005). Gases do efeito estufa e estoques de carbon nos solos: inventario do Brasil. *Cadernos de Ciência & Tecnologia*, 22(1), pp. 235–246.

Cambardella C.A., Elliott E.T. (1992). Particulate Soil Organic-Matter Changes across a Grassland Cultivation Sequence. *Soil Science Society of America Journal*, 56(3), pp.777–783. https://doi.org/10.2136/sssaj1992.03615995005600030017x

Canedoli C., Ferrè C., Abu El Khair D., Comolli R., Liga C., Mazzucchelli F., et al. (2020). Evaluation of ecosystem services in a protected mountain area: Soil organic carbon stock and biodiversity in alpine forests and grasslands. *Ecosystem Services*, 44, 101135. https://doi.org/10.1016/j.ecoser.2020.101135

Carpejani G., Assad A.S., Godoi L.R., Waters J., Andrade Guerra J.B.S.O. de (2020). The Anthropocene: Conceptual Analysis with Global Climate Change, Planetary Boundaries and Gaia 2.0. *Climate Change Management*, pp. 301–314. https://doi.org/10.1007/978-3-030-57235-8_24

Chabbi A., Lehmann J., Ciais P., Loescher H.W., Cotrufo M.F., Don A., et al. (2017). Aligning agriculture and climate policy. *Nature Climate Change*, 7(5), pp. 307–309. https://doi.org/10.1038/nclimate3286

Chan K.Y., Van Zwieten L., Meszaros I., Downie A., Joseph S. (2008). Using poultry litter biochars as soil amendments. *Soil Research*, 46(5), p. 437. https://doi.org/10.1071/SR08036

Chen Y., Liu J., Lv P., Gao J., Wang M., and Wang Y. (2018). IL-6 is involved in malignancy and doxorubicin sensitivity of renal carcinoma cells. *Cell Adhesion and Migration*, 12(1), pp. 28–36. https://doi.org/10.1080/19336918.2017.1307482

Climate Analysis Indicators Tool-CAIT 2.0 | NDC Partnership https://ndcpartnership.org/toolbox/climate-analysis-indicators-tool—cait-20.

Corbeels M., Cardinael R., Naudin K., Guibert H., Torquebiau E. (2019). The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. *Soil and Tillage Research*, 188, pp. 16–26. https://doi.org/10.1016/j.still.2018.02.015

Cotrufo M.F., Wallenstein M.D., Boot C.M., Denef K., Paul E. (2013). The Microbial Efficiency-Matrix Stabilization (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile plant inputs form stable soil organic matter? *Global Change Biology*, 19(4), pp. 988–995. https://doi.org/10.1111/gcb.12113

Eze S., Palmer S.M., and Chapman P.J. (2018). Soil organic carbon stock in grasslands: Effects of inorganic fertilizers, liming and grazing in different climate settings. *Journal of Environmental Management*, 223, pp. 74–84. https://doi.org/10.1016/j.jenvman.2018.06.013

Holl D., Wille C., Sachs T., Schreiber P., Runkle B. R. K., Beckebanze L., et al. (2019). A long-term (2002 to 2017) record of closed-path and open-path eddy covariance CO2 net ecosystem exchange fluxes from the Siberian Arctic. *Earth System Science Data*, 11(1), pp. 221–240. https://doi.org/10.5194/essd-11-221-2019

Houghton J., Callander B., and Varney S. (1992). Climate change 1992: the supplementary report to the IPCC scientific assessment.

Karelin D.V., Zamolodchikov D.G., Shilkin A.V., Popov S.Y., Kumanyaev A.S., de Gerenyu V.O.L., et al. (2020). The effect of tree mortality on CO2 fluxes in an old-growth spruce forest. *Eur J Forest Res,* 140, pp. 287–305. https://doi.org/10.1007/s10342-020-01330-3

Kleidon A. (2004). Beyond Gaia: Thermodynamics of Life and Earth System Functioning. *Climatic Change*, 66, pp. 271–319. https://doi.org/10.1023/B:CLIM.0000044616.34867.ec

Lal R. (2016). Beyond COP 21: Potential and challenges of the '4 per Thousand' initiative. *Journal of Soil and Water Conservation*, 71(1), 20A–25A. https://doi.org/10.2489/jswc.71.1.20A

Lal R., Fausey N. R., and Eckert D. J. (2018). Land Use and Soil Management Effects on Emissions of Radiatively Active Gases from Two Soils in Ohio. *Soil Management and Greenhouse Effect*, pp. 41–60.

Lehmann J. and Kleber M. (2015). The contentious nature of soil organic matter. *Nature*, 528, pp.60–68. https://doi.org/10.1038/nature16069

Makarova M.V., Poberovskii A.V., Yagovkina S.V., Karol I.L., Lagun V.E., Paramonova N.N., Reshetnikov A.I., Privalov V.I. (2006). Study of the formation of the methane field in the atmosphere over Northwestern Russia. *Izvestiya. Atmospheric and Oceanic Physics*, 42(2), pp. 215–227.

McNunn G., Karlen D.L., Salas W., Rice C.W., Mueller S., Muth D., et al. (2020). Climate smart agriculture opportunities for mitigating soil greenhouse gas emissions across the U.S. Corn-Belt. *Journal of Cleaner Production*, 268.

Noulèkoun F., Birhane E., Kassa H., Berhe A., Gebremichael Z. M., Adem N. M., et al. (2021). Grazing exclosures increase soil organic carbon stock at a rate greater than '4 per 1000' per year across agricultural landscapes in Northern Ethiopia. *Science of The Total Environment*, 782, 146821. https://doi.org/10.1016/j.scitotenv.2021.146821

Ogle S. M., Alsaker C., Baldock J., Bernoux M., Breidt F.J., McConkey B., et al. (2019). Climate and Soil Characteristics Determine Where No-Till Management Can Store Carbon in Soils and Mitigate Greenhouse Gas Emissions. *Scientific Reports*, 9, pp. 1–8. https://doi.org/10.1038/s41598-019-47861-7

Olson K.R., Ebelhar S.A., Lang J.M. (2010). Cover crop effects on crop yields and soil organic carbon content. *Soil Science*, 175(2), pp. 89–98. https://doi.org/10.1097/SS.0b013e3181cf7959

Parkin T.B., Kaspar T.C., Jaynes D.B., and Moorman T.B. (2016). Rye Cover Crop Effects on Direct and Indirect Nitrous Oxide Emissions. *Soil Science Society of America Journal*, 80(6), pp. 1551–1559. https://doi.org/10.2136/sssaj2016.04.0120

Poulton P., Johnston J., Macdonald A., White R., Powlson D. (2018). Major limitations to achieving '4 per 1000' increases in soil organic carbon stock in temperate regions: Evidence from long-term experiments at Rothamsted Research, United Kingdom. *Global Change Biology*, 24(6), pp. 2563–2584. https://doi.org/10.1111/gcb.14066

Rasse D.P., Rumpel C., Dignac M.F. (2005). Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant and Soil*, 269(1–2), pp. 341–356. https://doi.org/10.1007/s11104-004-0907-y

Reicosky D.C. (2001). Selected papers from the 10th International Soil Conservation Organization Meeting held May 24–29.

Reicosky D.C., Archer D.W. (2007). Moldboard plow tillage depth and short-term carbon dioxide release. *Soil and Tillage Research*, 94(1), pp. 109–121. https://doi.org/10.1016/j.still.2006.07.004

Reshetnikov A.I., Zinchenko A.V., Yagovkina S.V., Karol I.L., Lagun V.E., Paramonova N.N. (2009). Studying methane emission in the north of Western Siberia. *Russian Meteorology and Hydrology*, 34(3), pp.171–179. https://doi.org/10.3103/S1068373909030054

Reth S., Reichstein M., Falge E. (2005). The effect of soil water content, soil temperature, soil pH-value and the root mass on soil CO2 efflux – A modified model. *Plant and Soil*, 268, pp. 21–33. https://doi.org/10.1007/s11104-005-0175-5

Safonov S., Karelin D., Grabar V., Latyshev B., Grabovskii B., Uvarova N. et al. (2012). Carbon emission from the decomposition of dead wood in the southern taiga spruce forest. *Lesovedenie*, 5, pp. 75–80. (In Russ.)

La Scala N., Bolonhezi D., Pereira G.T. (2006). Short-term soil CO2 emission after conventional and reduced tillage of a no-till sugar cane area in southern Brazil. *Soil and Tillage Research*, 91(1–2), pp. 244–248. https://doi.org/10.1016/j.still.2005.11.012

Shukla M.K., Lal R. (2005). Erosional effects on soil organic carbon stock in an on-farm study on Alfisols in west central Ohio. *Soil and Tillage Research*, 81(2), pp. 173–181. https://doi.org/10.1016/j.still.2004.09.006

Snyder C.S. (2017). Enhanced nitrogen fertiliser technologies support the '4R' concept to optimise crop production and minimise environmental losses. *Soil Research*, 55(5–6), pp. 463–472. https://doi.org/10.1071/SR16335

Tei S., Morozumi T., Kotani A., Takano S., Sugimoto A., Miyazaki S., et al. (2021). Seasonal variations in carbon dioxide exchange fluxes at a taiga–tundra boundary ecosystem in Northeastern Siberia. *Polar Science*, 28, 100644. https://doi.org/10.1016/j.polar.2021.100644

Vakhin A.V., Aliev F.A., Mukhamatdinov I.I., Sitnov S.A., Sharifullin A.V., Kudryashov S.I., et al. (2020). Catalytic aquathermolysis of boca de jaruco heavy oil with nickel-based oil-soluble catalyst. *Processes*, 8(5). https://doi.org/10.3390/pr8050532

VandenBygaart A.J. (2018). Comments on soil carbon 4 per mille by Minasny et al. 2017. *Geoderma*, 309, pp. 113–114.

VandenBygaart A.J., Bremer E., McConkey B.G., Ellert B.H., Janzen H.H., Angers D.A., et al. (2011). Impact of Sampling Depth on Differences in Soil Carbon Stocks in Long-Term Agroecosystem Experiments. *Soil Science Society of America Journal*, 75(1), pp. 226–234. https://doi.org/10.2136/sssaj2010.0099

Varfolomeev M.A., Yuan C., Bolotov A.V., Minkhanov I.F., Mehrabi-Kalajahi S., Saifullin E.R., et al. (2021). Effect of copper stearate as catalysts on the performance of in-situ combustion process for heavy oil recovery and upgrading. *Journal of Petroleum Science and Engineering*, 207, 109125. https://doi.org/10.1016/j.petrol.2021.109125

de Vries W. (2018). Soil carbon 4 per mille: a good initiative but let's manage not only the soil but also the expectations: Comment on Minasny et al. (2017). *Geoderma,* 292, pp. 59–86. *Geoderma*, 309, pp. 111–112.

Wang Z., Hoffmann T., Six J., Kaplan J.O., Govers G., Doetterl S., et al. (2017). Human-induced erosion has offset one-third of carbon emissions from land cover change. *Nature Climate Change*, 7, pp. 345–349. https://doi.org/10.1038/nclimate3263

Xie H., Tang Y., Yu M., Geoff Wang G. (2021). The effects of afforestation tree species mixing on soil organic carbon stock, nutrients accumulation, and understory vegetation diversity on reclaimed coastal lands in Eastern China. *Global Ecology and Conservation*, 26, e01478. https://doi.org/10.1016/j.gecco.2021.e01478

Yuzbekov A.K., Zamolodchikov D.G., Ivashchenko A.I. (2014). Spruce fir photosynthesis in the forest ecosystems of the Log Tayezhnyi test area. *Moscow University Biological Sciences Bulletin*, 69(4), pp. 169–172.

Zagirova S., Mikhailov O., Elsakov V. (2020). Carbon dioxide, heat, and water vapor fluxes between a spruce forest and the atmosphere in Northeastern European Russia. *Biology Bulletin,* 47(3), pp. 306–317.

Zinchenko, A.V., Paramonova, N.N., Privalov, V.I. et al. (2008). Estimation of methane sources from concentration measurements in the area of gas production in the north of Western Siberia. *Russ. Meteorol. Hydrol*. 33, pp. 34–42. https://doi.org/10.3103/S1068373908010068

Zinchenko A.V., Paramonova N.N., Privalov V.I., Reshetnikov A.I. (2002). Estimation of methane emissions in the St. Petersburg, Russia, region: An atmospheric nocturnal boundary layer budget approach. *Journal of Geophysical Research: Atmospheres*, 107(20), ACH 2-1-ACH 2-11. https://doi.org/10.1029/2001JD001369

Zinchenko, A.V., Paramonova, N.N., Privalov, V.I. et al. (2001). Estimation of methane emission from surface concentrations in St. Petersburg and its environs. *Meteorologiya i gidrologiya*, 5, pp. 35–39. (In Russ.)

About the Authors

Danis K. Nurgaliev – DSc (Geology and Mineralogy), Professor, Director of the Institute of Geology and Petroleum Technologies, Vice-Rector for Oil and Gas Technologies, Nature Management and Earth Sciences

Kazan Federal University

7, Chernyshevsky St., Kazan, 420111, Russian Federation

Svetlana Yu. Selivanovskaya – DSc (Biology), Professor, Director of the Institute of Environmental Sciences, Kazan Federal University

5, Tovarishcheskaya St., Kazan, 420097, Russian Federation

Maria V. Kozhevnikova– PhD. (Biology), Deputy Director, Institute of Environmental Sciences

Kazan (Volga Region) Federal University

5, Tovarishcheskaya St., Kazan, 420097, Russian Federation

Polina Yu. Galitskaya – DSc (Biology), Professor, Applied Ecology Department, Institute of Environmental Sciences

Kazan (Volga Region) Federal University

5, Tovarishcheskaya St., Kazan, 420097, Russian Federation

Manuscript received 2 August 2021;
Accepted 9 August 2021;
Published 30 August 2021