Global Approaches to Reaching Carbon Neutrality: A Review of Strategies and Policies

Bekmurzaeva Rashiya[1,*] *Oksana* Mukhoryanova [2] , *Polina* Shmygaleva [2]

[1]Kadyrov Chechen State University, Grozny, Russia
[2] Stavropol branch of RANEPA, Stavropol, Russia

Abstract. Achieving carbon neutrality has become a global imperative to mitigate the adverse effects of climate change. This paper explores strategies adopted by nations, industries, and communities worldwide to achieve net-zero greenhouse gas emissions. Key approaches include transitioning to renewable energy sources, improving energy efficiency, implementing carbon capture and storage (CCS) technologies, promoting reforestation and afforestation, and embracing circular economy practices. Additionally, policy-driven initiatives such as carbon pricing, international cooperation, and stringent regulations play a critical role in fostering sustainable practices. The study highlights successful examples, challenges faced, and the need for tailored solutions for diverse economic and social contexts. By emphasizing the integration of technological innovation, policy frameworks, and public engagement, this paper underscores the importance of collective efforts to achieve carbon neutrality and ensure a sustainable future for the planet.

1 Introduction

The rapid pace of global industrialization and the excessive reliance on non-renewable energy sources have resulted in significant greenhouse gas emissions, leading to a rise in global temperatures and widespread environmental degradation. Since the pre-industrial era around 1850, the global average atmospheric carbon dioxide (CO2) concentration has increased markedly, from 285 ppm to 419 ppm by 2022. According to the United Kingdom Meteorological Office, this has caused the global average surface temperature to rise by approximately 0.97 to 1.21°C between 1850 and 2022, with a central estimate of 1.09°C. Additionally, 2022 is projected to continue the trend of being among the warmest years on record. Global greenhouse gas emissions, driven primarily by CO2 emissions from the use of non-renewable energy, are expected to increase by 50% by 2050.

* Corresponding author: raya.bek@yandex.ru

Without effective strategies or technologies to mitigate CO2 emissions, atmospheric CO2 levels, along with global surface and ocean temperatures, will continue to rise. The resulting temperature increase has already caused extensive harm to ecosystems and human environments, including species extinction, loss of biodiversity, droughts, floods, wildfires, ocean acidification, melting of polar ice caps, and rising sea levels. In response to these escalating challenges, 197 member states of the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement on December 12, 2015, during the Paris Climate Conference (COP21). The agreement commits countries to limit global temperature increases to below 2°C, with efforts to cap the rise at 1.5°C. By February 2021, 124 nations had declared their commitment to achieving carbon neutrality and reaching net-zero carbon emissions by mid-century. Achieving the targets outlined in the Paris Agreement requires not only the reduction of CO2 emissions but also the removal of CO2 from the atmosphere to achieve net-zero or even negative emissions. Carbon neutrality—defined as a balance between the amount of CO2 emitted and removed—can be accomplished through measures such as carbon offsetting and sequestration initiatives. The Intergovernmental Panel on Climate Change (IPCC), in its special report on global warming of 1.5°C, emphasized the need to phase out fossil fuels, expand renewable energy usage, improve energy efficiency, and implement these measures within urban areas. Additionally, the promotion of carbon removal or sequestration in terrestrial and marine ecosystems is crucial for sustainable development and achieving net-zero emissions. While various countries, regions, and cities have developed strategies to enhance carbon sequestration and achieve carbon neutrality, significant challenges remain. These include economic, technological, and social barriers that necessitate coordinated global efforts and innovative solutions.

This literature review provides a comprehensive analysis of the outcomes of the 26th United Nations Climate Change Conference (COP26) in the context of achieving carbon neutrality, with a focus on the goal of reaching net-zero emissions by 2050 or 2060 for most participating nations. It examines global initiatives, highlighting policies and measures implemented by individual countries to achieve this target. The review also explores the interconnections and synergies between adaptation and mitigation strategies, identifies direct and indirect sources of carbon emissions, and outlines two primary pathways to carbon neutrality: emissions reduction and atmospheric carbon removal.

In addition, the review presents carbon-neutral strategies across key sectors such as transportation, agriculture, food waste management, and industry, while conducting a life cycle analysis of various technologies and approaches designed to achieve these goals. By offering up-to-date insights into relevant policies and technologies, the review aims to assist governments and stakeholders in different regions in understanding the environmental, social, and economic benefits of transitioning to carbon neutrality.

2 Research methodology

The research methodology of this study is based on three key methods: systematic literature review, comparative analysis, and case study examination. The first method, a systematic literature review, involved identifying, collecting, and analyzing relevant academic articles, government reports, and policy documents from reputable databases such as Scopus, PubMed, and Web of Science. This helped to establish a comprehensive understanding of global strategies and technologies for achieving carbon neutrality, as well as the outcomes of

international agreements like COP26. The second method, comparative analysis, was employed to evaluate the differences and similarities in carbon-neutral strategies implemented across various countries and regions. This method focused on identifying common trends, challenges, and innovative approaches in policy-making, technological adoption, and sector-specific measures such as energy, transportation, and agriculture. The third method, case study examination, involved a detailed analysis of real-world examples where specific carbon-neutral initiatives were implemented. This approach allowed for an in-depth understanding of the effectiveness of particular strategies, technologies, or policies, providing valuable insights into best practices and potential barriers. Together, these methods provide a robust framework for evaluating the pathways to achieving carbon neutrality and their environmental, social, and economic impacts globally.

3 Results and Discussions

On October 13, 2021, Russian President Vladimir Putin announced Russia's intention to achieve carbon neutrality by 2060 during the Russian Energy Week. To support this goal, the Ministry of Economic Development developed the Strategy for the Socioeconomic Development of Russia with Low Greenhouse Gas Emissions until 2050 (SNUR), which was approved by the government on October 29, 2021 (Order No. 3052-r). Shortly thereafter, the draft operational plan for implementing this strategy began gaining attention in expert discussions.

Both the strategy and the draft operational plan contain numerous unprecedented quantitative assessments and proposed actions to meet the outlined goals. However, it is worth noting that achieving carbon neutrality is not currently subject to standardized methodological guidelines under the Paris Agreement or other internationally recognized documents. This lack of regulation introduces potential risks, including the possibility of "greenwashing" claims. Consequently, it is essential to preliminarily evaluate the adequacy and scientific credibility of the proposed pathways and mechanisms for achieving Russia's carbon neutrality targets.

Environmental degradation and global warming represent two of the most critical ecological challenges confronting humanity today. Without decisive global action, including targeted policies, initiatives, and measures, the worsening environmental conditions will continue to jeopardize the well-being of future generations. The ongoing reliance on fossil fuels has driven global carbon dioxide emissions to unprecedented levels, reaching their peak in 2020. This increase has significantly contributed to global warming, sparking a worldwide call to reduce fossil fuel consumption and implement climate agreements. One such agreement is the Paris Accord (Nations, 2015), which sets a goal of limiting global temperature rise to below 1.5°C, urging countries to adopt effective measures to reduce carbon emissions and eventually achieve carbon neutrality. However, pathways to these goals vary significantly across regions, cities, and institutions.

For example, China's government has introduced the "Guidance on Accelerating the Establishment of a Sound Green Low-Carbon Circular Development Economic System," aiming for peak carbon emissions by 2030 and carbon neutrality by 2060, while progressing toward net-zero CO2 emissions. In Nordic countries, Pigouvian tax systems have been adopted to encourage carbon reduction through fiscal measures. Similarly, research from Australia by Sen et al. (2022) emphasizes the role of educational institutions in spreading awareness and knowledge about carbon neutrality, underscoring how such initiatives vary widely yet align toward the shared goal of climate mitigation.

An analysis of carbon neutrality efforts among 198 countries shows varying levels of progress. As of February 2022, nations such as Bhutan, Gabon, and Suriname have already achieved carbon neutrality, while 21 others, including South Africa, India, and Australia, have pledged to reach this milestone between 2030 and 2070. Additionally, 17 countries, including Germany, Canada, and Japan, have enacted carbon-neutral legislation, and 58 more, such as the United States, China, and Finland, have incorporated carbon neutrality into their policy frameworks. The remaining countries are in the process of drafting or discussing strategies to meet these targets.

Out of the 198 committed nations, 4.5% have already attained carbon neutrality, 10.6% have formally declared goals, 8.6% have passed relevant legislation, and 29.3% have developed specific policies. Meanwhile, 47% are in preliminary stages of discussing or proposing measures. Notably, 60.6% of these countries aim to achieve carbon neutrality by 2050–2070. This analysis underscores the global efforts underway to combat climate change, while also highlighting the urgent need for continued progress and collaboration to realize a sustainable, carbon-neutral future.

According to the SNUR, achieving carbon neutrality by 2060 would require reducing industrial emissions from 2.1 billion tons to 1.2 billion tons. In parallel, carbon sequestration by ecosystems would need to increase from 535 million tons to 1.2 billion tons (Fig. 1).

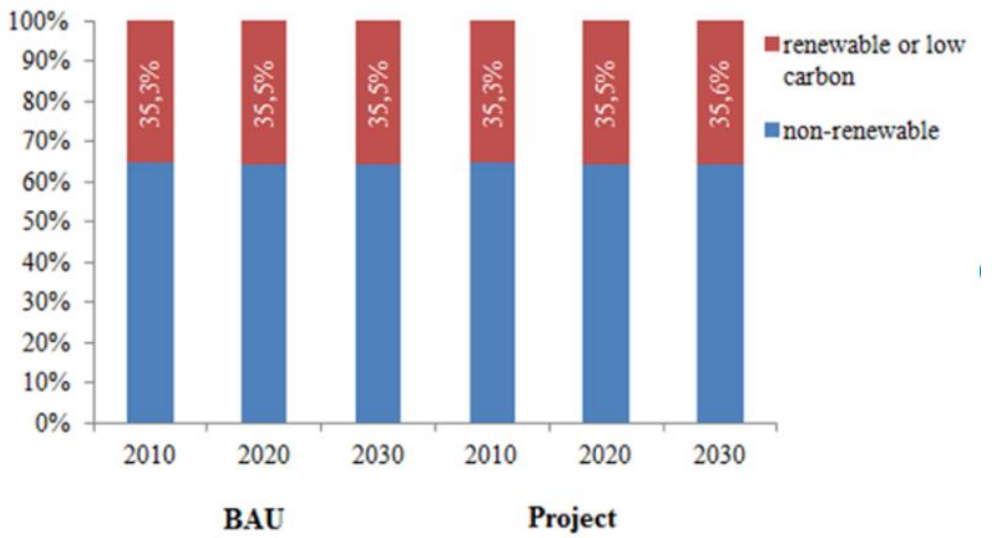

Figure 1. Changes in low-carbon technology ratios in the sector until 2030

In our view, reaching this goal is an exceptionally ambitious and unprecedented challenge. It is worth noting that, despite extensive efforts, the launch of federal programs, and significant investments in forest fire prevention and suppression over the past decade, forest flammability—and consequently, greenhouse gas emissions from forest fires—has only risen. Moreover, forest flammability has also increased in other nations, including economically developed countries such as Canada. The authors analyzed the expected outcomes of the planned activities outlined in the draft Operational Plan of the SNUR [2], assessing the

qualitative and quantitative risks of potential partial or total failure to achieve them. We have consciously acknowledged certain limitations; for instance, based on statistics, it can be presumed that emissions from logging will remain largely unchanged. While the reliability of various data sources may be debated, such as the objectivity of official data on the implementation of transferred powers by Russian Federation subjects, space monitoring data from the Federal Forestry Agency's Remote Monitoring Information System (ISDM) generally show similar trends in forest fire areas (Fig. 2).

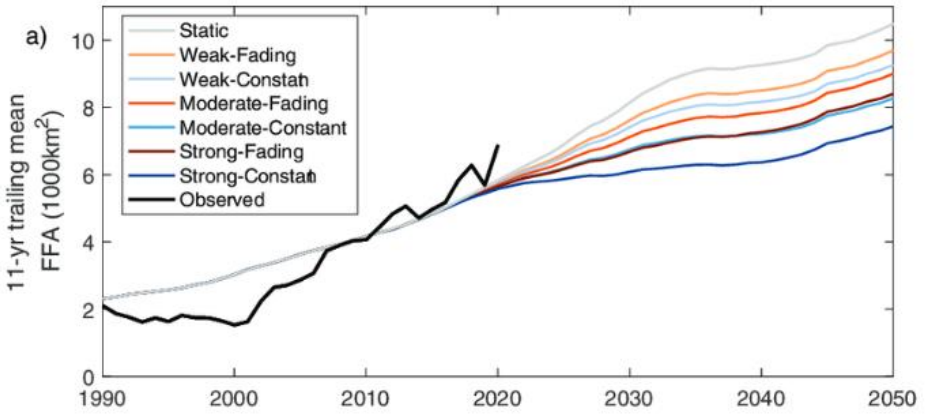

Figure 2. Shown are time series of trailing 11-year moving average forest-fire area, b average annual forest-fire area, c interquartile range, median and the 10th and 90th percentile for the average annual burned area, d recurrence interval of the forest-fire area exceeding the 2020 fire season.

The SLR (State Forest Registry) uses the term "burnt areas" to refer to regions that have experienced significant damage from fires, specifically those caused by crown fires and high-intensity ground fires. These are the types of fires that lead to complete destruction of vegetation, thus creating burnt areas. However, the issue lies in the fact that forest fire emissions are not solely a result of these intense fires but also arise from all fires that occur in forested areas. Therefore, the SLR's use of "burnt areas" does not account for the full extent of emissions produced by forest fires, especially those that are of lower intensity.

In reality, up to 70-90% of the areas that are covered by fires are affected by low- and medium-intensity ground fires, which do not result in the creation of burnt areas. These fires, though less destructive, still release greenhouse gases into the atmosphere. However, since these fires do not result in burnt areas, they are not considered in the SLR's data, thus underestimating the full impact of forest fires on emissions.

We propose that the materials and data from the ISDM-Rosleskhoz (Information System of Remote Forest Monitoring) will, in the near future, become the key tool for calculating forest fire emissions in the national greenhouse gas inventory. Currently, Rosleskhoz, the Russian Federal Forestry Agency, utilizes the ISDM system for forest fire monitoring. According to this system, there is a significant discrepancy between the areas affected by forest fires and the areas classified as burnt. The difference can be as much as three times the size of the areas recognized as burnt in the SLR data.

Moreover, while the SLR data primarily measures emissions resulting from crown fires and high-intensity ground fires, which are responsible for burnt areas, the actual greenhouse gas

emissions from these types of fires are considerably higher compared to emissions from low- and medium-intensity fires. These lower-intensity fires do not lead to the formation of burnt areas, yet they still produce greenhouse gases. Therefore, it is crucial to recognize that the true emissions from forest fires are likely much higher than current SLR estimates, which focus only on high-intensity fires.

This discrepancy in fire intensity and emissions data highlights the need for more accurate and comprehensive monitoring systems like ISDM-Rosleskhoz, which can provide a fuller picture of the greenhouse gas emissions caused by forest fires. The development and implementation of such systems will play a crucial role in the accurate assessment of emissions in the national greenhouse gas cadastre and ultimately contribute to better understanding and mitigating the impacts of forest fires on climate change.

Achieving carbon neutrality is becoming a central goal for countries globally, with strategies emerging across various sectors such as energy, industry, agriculture, and land use. This section explores global strategies, with a particular focus on Russia's efforts and challenges in meeting carbon neutrality goals by 2060.

1. Transition to Renewable Energy

The transition to renewable energy is one of the most widely adopted strategies for achieving carbon neutrality. Many countries are investing heavily in solar, wind, hydro, and geothermal energy. For instance, the European Union has set ambitious targets to decarbonize its energy sector, aiming for 32% of energy to come from renewables by 2030, with some countries, like Denmark, achieving higher shares of renewables in their energy mix. Similarly, China, as the world's largest emitter of CO2, has been rapidly expanding its renewable energy sector, aiming for 20% of its energy consumption to come from renewable sources by 2025.

In Russia, the country has made some strides in the energy sector, but the reliance on fossil fuels remains dominant. Russia is the world's largest natural gas exporter and one of the top oil producers, making the transition to renewables more challenging. However, Russia has begun exploring renewable energy sources, particularly in the Arctic and Far East regions, with large-scale wind and solar power projects. The Russian government's "Energy Strategy to 2035" outlines plans to diversify the energy sector, though it continues to face significant barriers such as the underdeveloped infrastructure for renewable energy and the country's heavy dependence on fossil fuels.

2. Carbon Pricing and Market-Based Mechanisms

Carbon pricing, including carbon taxes and emissions trading systems (ETS), is another key strategy for achieving carbon neutrality. Countries like Sweden and Canada have implemented high carbon taxes that incentivize businesses to reduce their carbon emissions. In the European Union, the EU ETS has been instrumental in reducing emissions by setting a cap on the total amount of greenhouse gases that can be emitted by installations covered by the system. Through cap-and-trade, companies that reduce their emissions below their allocation can sell their excess allowances, encouraging emissions reductions.

In Russia, however, carbon pricing mechanisms are still in early development. Although the Russian Federation has signed the Paris Agreement and committed to reducing greenhouse gas emissions, the implementation of a comprehensive carbon pricing system remains a topic of discussion. There is a lack of strong market-based mechanisms in place, with Russia's focus remaining on economic growth driven by its fossil fuel exports. However, some experts have suggested that carbon taxes could help Russia achieve its carbon neutrality goals, particularly by driving more energy efficiency in industries.

3. Carbon Capture and Storage (CCS)

Carbon capture and storage (CCS) is a technology aimed at capturing carbon dioxide emissions from major industrial sources and storing them underground to prevent their release into the atmosphere. Countries like Norway have implemented successful CCS projects, with the Sleipner gas field serving as a model for CO2 storage. The U.S. has also invested in CCS, particularly for industries like cement and steel manufacturing that are difficult to electrify.

Russia has vast potential for CCS, especially in its oil and gas fields. The country has begun to explore CCS technologies, particularly through partnerships with international companies. The Kharampur and Yamburg fields, two major gas fields in Siberia, are among the locations where Russia has considered implementing CCS projects. However, the lack of domestic funding for large-scale CCS infrastructure and the high costs associated with the technology present significant challenges. Additionally, Russia has yet to establish a regulatory framework to support the widespread adoption of CCS, making it difficult to achieve carbon neutrality without further investment in this area.

4. Sustainable Agriculture and Land Use

Sustainable land use and agricultural practices play a significant role in achieving carbon neutrality, particularly through measures like reforestation, agroforestry, and soil carbon sequestration. In the European Union, countries such as France and Germany have integrated sustainable land management practices into their climate strategies. Initiatives like the EU's Common Agricultural Policy (CAP) provide financial incentives for farmers to implement sustainable practices that reduce emissions and increase carbon storage in soils.

Russia, with its vast land area and forests, has an important role to play in global carbon sequestration. The country is home to about 20% of the world's forest cover, and its forests serve as significant carbon sinks. However, Russia has faced challenges with deforestation, wildfires, and land degradation, which have increased greenhouse gas emissions. The Russian government has launched several reforestation and afforestation projects to combat these issues, but forest fires and logging continue to contribute to emissions. Efforts to implement sustainable agricultural practices have been slower in Russia compared to Western countries, though there is growing recognition of the need to enhance soil carbon sequestration and reduce emissions from land-use changes.

5. Energy Efficiency Improvements

Improving energy efficiency in industries, buildings, and transportation is another crucial strategy for reducing emissions. Countries around the world are investing in energy-efficient technologies, with the EU's "Green Deal" promoting energy savings across all sectors. The adoption of energy-efficient building standards, the introduction of electric vehicles (EVs), and the expansion of public transportation systems are key elements of these efforts.

Russia has made some progress in energy efficiency, particularly in the building sector, where energy-efficient standards are becoming more widely adopted. However, the energy efficiency of Russian industry remains low compared to Western standards. The Russian government has set ambitious targets to improve energy efficiency by 2030, but significant challenges remain in sectors such as manufacturing and transportation. The widespread adoption of electric vehicles, for example, faces obstacles such as underdeveloped charging infrastructure and the dominance of gasoline-powered cars.

6. Policy and International Cooperation

International cooperation plays a critical role in achieving carbon neutrality, as climate change is a global issue that requires coordinated efforts. The Paris Agreement, adopted in 2015, marked a milestone in global climate policy, with nearly every country committing to reduce greenhouse gas emissions and work toward carbon neutrality. The agreement's goal of

limiting global temperature rise to below 2°C, and ideally 1.5°C, has driven numerous national strategies.

Russia has been an active participant in international climate negotiations but has been cautious about adopting aggressive climate policies. While the country has ratified the Paris Agreement, there remains skepticism regarding its commitment to strict emission reductions, given its reliance on fossil fuel exports. However, there is an increasing recognition within Russia of the economic and environmental benefits of achieving carbon neutrality, and the government has begun to outline strategies for this transition.

4 Conclusions

Achieving carbon neutrality by 2060 is an ambitious goal for Russia, as well as for other countries around the world. Strategies that focus on renewable energy adoption, carbon pricing, CCS technologies, sustainable land use, and energy efficiency are essential for reducing emissions and meeting international climate targets. However, Russia faces significant challenges due to its heavy reliance on fossil fuels, underdeveloped renewable energy infrastructure, and the political and economic complexities of implementing carbon-neutral policies. International cooperation and domestic investment in clean technologies and carbon management strategies will be crucial in ensuring that Russia and the global community can meet the targets set out in the Paris Agreement and work towards a sustainable future.

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