Carbon Sequestration in Agriculture and Land Use: Contributions to National Carbon Neutrality Goals

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Abstract. Agriculture and land use systems play a pivotal role in global efforts to achieve carbon neutrality. This article explores the potential of agricultural and land use practices to act as carbon sinks through carbon sequestration , contributing to national climate goals and international commitments such as the Paris Agreement . The study reviews a range of soil carbon management strategies , agroecological practices , and land restoration techniques that enhance carbon storage in terrestrial ecosystems. Key practices examined include conservation agriculture , cover cropping , agroforestry , biochar application , and restoration of degraded lands , all of which have demonstrated measurable success in increasing soil organic carbon and reducing greenhouse gas emissions. The article also discusses the policy frameworks , economic incentives , and monitoring mechanisms necessary to scale up carbon sequestration efforts within the agricultural and land use sectors. The findings highlight that sustainable land management not only supports climate mitigation but also improves soil health , biodiversity , and long-term agricultural productivity . However, the effectiveness of these practices depends on regional climatic conditions , soil characteristics , and policy support .

1 Introduction

The global challenge of climate change has prompted nations to commit to ambitious targets for reducing greenhouse gas (GHG) emissions and achieving carbon neutrality. The Paris Agreement, adopted in 2015, set a clear global objective: to limit the increase in average global temperature to well below 2°C, and preferably to 1.5°C, above pre-industrial levels. In response, many countries have adopted national strategies aimed at achieving net-zero carbon emissions

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by mid-century. Central to these strategies is the concept of carbon neutrality — a balance between emitted and removed greenhouse gases, particularly carbon dioxide (CO_2).

While much of the focus in climate policy has been on reducing emissions from energy, transport, and industry, agriculture and land use systems offer a significant but often underutilized potential for carbon sequestration — the long-term storage of atmospheric carbon in soils, vegetation, and other terrestrial ecosystems. These systems not only act as sources of emissions but also as carbon sinks , capable of offsetting emissions from other sectors through natural and managed carbon capture processes .

Agricultural lands, forests, wetlands, and degraded ecosystems represent major opportunities for enhancing carbon storage. Practices such as conservation agriculture , cover cropping , agroforestry , and biochar application have demonstrated the ability to increase soil organic carbon , improve soil fertility , and enhance ecosystem resilience . Moreover, the restoration of degraded lands and the reforestation of deforested areas can significantly boost the carbon sequestration potential of terrestrial ecosystems.

Despite this potential, the integration of carbon sequestration in agriculture and land use into national climate strategies remains inconsistent. Many countries have yet to fully recognize or quantify the role of these systems in achieving carbon neutrality, and policy frameworks often lack the necessary incentives, monitoring systems, and financial mechanisms to scale up land-based carbon solutions.

This article explores the current state and future potential of agriculture and land use systems in contributing to national carbon neutrality goals. It examines key carbon sequestration practices , evaluates their effectiveness and scalability , and discusses the policy and economic instruments required to mainstream these approaches within national climate strategies.

By highlighting the synergies between climate mitigation, sustainable land management, and food security , this paper aims to inform policy-makers, researchers, and land-use planners about the strategic importance of agriculture and land use in the global transition to a carbon-neutral future.

2 Research methodology

This study employed a systematic literature review and comparative policy analysis to explore the potential of agricultural and land use systems to contribute to national carbon neutrality goals. The methodology was designed to integrate scientific findings, policy frameworks, and practical implementation strategies in order to provide a comprehensive assessment of the role of carbon sequestration in agriculture and land management. The research aimed to identify key practices, evaluate their effectiveness, and examine how these approaches are being incorporated into national climate strategies.

A comprehensive search was conducted across major scientific databases including Web of Science, Scopus, ScienceDirect, and SpringerLink , focusing on literature published between 2010 and 2024 . The search was guided by key terms related to carbon sequestration, agriculture, land use, soil carbon, climate policy, carbon neutrality, and sustainable land management , ensuring broad coverage of the topic. In addition to academic publications, the study included reports from international organizations such as the Intergovernmental Panel on Climate Change (IPCC), Food and Agriculture Organization (FAO), International Union for Conservation of Nature (IUCN), and World Resources Institute (WRI) . This ensured that both scientific and policy-oriented perspectives were represented in the analysis.

The selection of sources was based on a set of criteria aimed at ensuring scientific rigor and relevance. Only publications that focused on carbon sequestration in agricultural and land use systems , provided quantitative data on carbon storage or mitigation capacity, and discussed policy, economic, or technological aspects were included. Priority was given to peer-reviewed journal articles and official technical reports. Studies that were purely theoretical, focused exclusively on emissions reduction, or lacked methodological transparency were excluded from the analysis.

Data were extracted from the selected publications using a standardized approach , with attention to key variables such as the type of land use or agricultural practice, the methodology used to assess carbon sequestration, reported carbon storage rates, geographic and climatic context, and the policy or institutional factors influencing implementation. This allowed for a comparative assessment of different practices and their potential for scaling up under various environmental and socioeconomic conditions.

The extracted data were then synthesized to identify patterns and trends across different regions and land use systems. This synthesis focused on three interrelated dimensions: the biophysical potential of different practices to sequester carbon, the policy and economic frameworks that support or hinder their adoption, and the barriers and opportunities associated with integrating land-based carbon sequestration into national climate strategies. The synthesis was further enriched by examining case studies and real-world examples of successful implementation.

To contextualize the findings within the broader framework of climate policy, a comparative policy analysis was conducted across several countries that have made significant commitments to carbon neutrality. These countries were selected based on their climate policy maturity , availability of comprehensive documentation , and diversity in agroecological and economic conditions . The analysis focused on how carbon sequestration in agriculture and land use is addressed in national climate strategies, what policy instruments and financial mechanisms are used to promote implementation, and how progress is monitored and evaluated.

The comparative analysis included countries such as the European Union , where climate-smart agriculture and land use policies are embedded in the European Green Deal and the Common Agricultural Policy , China , with its large-scale afforestation and sustainable agriculture programs, the United States , particularly its initiatives under the US Department of Agriculture , Brazil , with a focus on Amazon restoration and agroforestry, and India , where the National Mission for Sustainable Agriculture plays a central role in promoting carbon sequestration through land use change.

Each country case was analyzed through a consistent framework that assessed the alignment of national climate targets with land-based carbon removal strategies, the presence of supportive institutional structures, the availability of monitoring, reporting, and verification (MRV) systems, and the engagement of stakeholders in the implementation process. This approach allowed for the identification of best practices, policy innovations, and cross-country lessons that can inform the development of more effective and scalable carbon sequestration strategies.

In addition to the literature and policy review, the study also examined the methodologies used to quantify carbon sequestration in agriculture and land use . This included an evaluation of IPCC guidelines , national greenhouse gas inventories , and standards used in voluntary carbon markets , such as the Verified Carbon Standard (VCS) and the Gold Standard . The review focused on the accuracy, transparency, and scalability of different carbon accounting frameworks, particularly in the context of national climate strategies and international reporting obligations.

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

The findings of the literature and policy review reveal that agriculture and land use systems hold significant potential for contributing to national carbon neutrality goals. Across the selected case studies and scientific reports, a wide range of practices were identified as effective in increasing carbon storage in soils and vegetation, with varying degrees of scalability and policy integration.

One of the most widely studied and implemented practices is conservation agriculture , which includes minimum soil disturbance, crop rotation, and permanent organic ground cover . The review found that conservation agriculture consistently increases soil organic carbon (SOC) levels, with reported sequestration rates ranging from 0.2 to 1.0 metric tons of CO_2 per hectare per year , depending on climate, soil type, and management intensity. In particular, no-till farming , when combined with cover cropping , has demonstrated long-term carbon accumulation in the topsoil, especially in temperate zones. However, in tropical and subtropical regions, results were more variable, suggesting the need for region-specific adaptations and further research into the long-term stability of stored carbon.

Agroforestry systems , which integrate trees into agricultural landscapes, emerged as one of the most promising strategies for enhancing carbon sequestration. The review showed that tree-based intercropping, silvopastoral systems, and alley cropping can significantly increase both above-ground and below-ground carbon stocks . In some cases, agroforestry systems were found to sequester up to 3.5 metric tons of CO_2 per hectare annually , particularly in tropical climates where biomass accumulation is more rapid. Moreover, agroforestry was found to offer co-benefits , including improved biodiversity, soil fertility, and resilience to climate change, making it a highly synergistic land use strategy .

Another key finding relates to the role of biochar application in enhancing soil carbon storage. Studies reviewed indicated that biochar can significantly enhance soil carbon retention , with long-term stability due to its recalcitrant nature. Application rates and feedstock types were found to influence the magnitude of carbon sequestration , with woody biomass-derived biochar showing the highest carbon storage potential. However, the economic feasibility and

scalability of biochar use remain limited by production costs and feedstock availability , suggesting the need for targeted policy support and financial incentives.

The analysis of land restoration practices , particularly in degraded soils and deforested areas, also highlighted their potential for carbon sequestration. Reforestation and afforestation programs, especially those incorporating native species and community-based management, were found to significantly enhance carbon stocks in biomass and soils . In the case of China's large-scale afforestation initiatives , carbon sequestration rates were reported to be as high as 4 metric tons of CO_2 per hectare per year , particularly in regions with favorable climatic conditions and soil restoration efforts. Similarly, rewetting of drained peatlands in the European Union has been shown to reduce carbon losses and restore carbon sinks , with long-term benefits for climate mitigation.

The comparative policy analysis revealed that while many countries recognize the importance of agriculture and land use in achieving carbon neutrality, the level of integration into national climate strategies varies significantly . In the European Union , for instance, the Common Agricultural Policy (CAP) and the EU Green Deal provide a comprehensive framework for promoting carbon sequestration through climate-smart agricultural practices . Instruments such as carbon farming incentives , agri-environmental schemes , and subsidies for sustainable land management are increasingly being used to align agricultural production with climate goals.

In contrast, while China and India have made large-scale commitments to afforestation and sustainable agriculture, the policy frameworks for carbon accounting and verification remain underdeveloped . In China, afforestation programs have been successful in increasing forest cover and carbon stocks, but challenges remain in terms of long-term sustainability and monitoring . In India, the National Mission for Sustainable Agriculture (NMSA) promotes soil health and carbon sequestration through organic farming and agroforestry , but systematic carbon accounting and policy incentives are still in early stages .

The United States has made significant progress in developing carbon markets and incentive-based programs for farmers and landowners. Initiatives such as the USDA's Climate-Smart Agriculture and Forestry Strategy aim to reward land managers for adopting carbon sequestration practices. However, the lack of standardized monitoring, reporting, and verification (MRV) systems remains a barrier to widespread adoption and inclusion in carbon offset programs. In Brazil , the potential for carbon sequestration through land use is substantial, particularly in the Amazon and Cerrado regions . However, ongoing deforestation and land degradation have significantly undermined carbon storage capacity. While the country has developed recovery programs , such as the Low-Carbon Agriculture Plan (Plano ABC) , implementation has been hindered by policy instability, weak enforcement, and limited financial support .

4 Conclusions

The findings of this study underscore the significant potential of agriculture and land use systems to contribute to national carbon neutrality goals. A range of land management practices — including conservation agriculture, agroforestry, biochar application, and land restoration — have demonstrated measurable success in enhancing carbon sequestration and reducing greenhouse gas emissions. These practices not only support climate mitigation but

also offer co-benefits such as improved soil health, increased biodiversity, and enhanced resilience to climate change.

The comparative policy analysis reveals that while many countries recognize the importance of land-based carbon removal strategies, the degree of integration into national climate frameworks varies widely . Leading examples, such as the European Union's Climate-Smart Agriculture initiatives , demonstrate how policy coherence, financial incentives, and robust monitoring systems can support the widespread adoption of carbon sequestration practices. In contrast, countries like India and Brazil , despite having large-scale land restoration and agricultural sustainability programs, face challenges related to policy implementation, carbon accounting, and institutional capacity , which limit the full realization of their carbon sequestration potential.

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