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Economic impact of greenhouse gas emissions in agricultural production: Challenges and policy responses

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Abstract

While the agricultural sector is indispensable for meeting the increasing global demand for food, it simultaneously contributes a substantial share to global greenhouse gas (GHG) emissions. Specifically, agricultural activities are among the leading sources of methane (CH4) and nitrous oxide (N2O), which possess significantly higher global warming potential than carbon dioxide (CO2). This dual role positions agriculture as both a driver and a victim of climate change. This study comprehensively analyzes the complex economic impacts of GHG emissions originating from agricultural production, identifies the key challenges to mitigation, and evaluates the array of policy responses developed to address these issues. The economic repercussions are explored through the lens of production losses caused by climate change, increasing operational costs for farmers due to new practices and potential carbon pricing, and heightened pressures on international trade and competitiveness. The main challenges to effective mitigation are structural, primarily related to technology adoption across diverse farm types, securing adequate financing, and achieving necessary policy alignment across multiple government sectors. The policy response section details the potential of Climate-Smart Agriculture (CSA), the application of carbon pricing and market-based mechanisms, and the implementation of supportive regulatory and international trade measures. The study ultimately underscores the critical necessity of developing and implementing comprehensive, integrated policies that harmoniously embed emission reduction goals with crucial objectives such as economic development and food security to ensure the long-term sustainability and resilience of the global agricultural system.

Keywords: Agricultural Emissions , Climate-Smart Agriculture (CSA) , Economic Impact
Jel codes: Q1, Q54, Q58

1. Introduction

Greenhouse gas (GHG) emissions are the unequivocal main driver of global warming. Alongside the energy and transportation sectors, the agricultural sector contributes substantially to this global challenge. Current estimates suggest that up to one-quarter of global GHG emissions originate from the broader food and agricultural systems. The composition of these emissions is particularly concerning: a significant portion consists of methane (CH_4) from enteric fermentation in livestock, nitrous oxide (N_2O) primarily from the application of nitrogen fertilizers and soil management practices, and carbon dioxide (CO_2) released through energy use and land-use change, notably deforestation and soil disturbance (Sokal, K. & Kachel, M. 2025).

The resulting climate change and the need to mitigate its causes impose wide-ranging economic impacts on the sector. Firstly, climate change itself acts as a massive externality, directly reducing agricultural productivity and increasing volatility through shifts in temperature and rainfall patterns, the increasing frequency of extreme events like droughts and floods, and the proliferation of pests and diseases (Habib-ur-Rahman M et all., 2022; Ağaçayak, T., Öztürk, L., 2017). Secondly, the policies and practices essential for reducing emissions impose new costs, investment requirements, and changes in practice on farmers and the entire agricultural value chain. This paper is dedicated to a detailed examination of this dual economic burden stemming from agricultural GHG emissions and the exploration of the accompanying policy, structural, and implementation challenges inherent in the global transition to a low-carbon food system.

2. Economic Impacts of GHG Emissions in Agricultural Production

The economic impact of GHG emissions in the agricultural sector manifests as both direct and indirect costs.

2.1. Climate-Induced Production and Yield Losses

The primary economic consequence of climate change is the decline in agricultural productivity. In food-insecure regions such as Asia, climate-related extreme events—droughts, heatwaves, and erratic rainfall—cause significant crop and livestock losses (Habib-ur-Rahman M et all., 2022). Models indicate that climate change has hindered global agricultural productivity growth over the past fifty years (Sokal, K. & Kachel, M.2025). For example, significant yield losses have been documented in cereal production (Habib-ur-Rahman M et all., 2022). These losses reduce farmers' income, increase food prices, and contribute to macroeconomic instability.

2.2. Rising Costs and the Need for Technology Investment

Adoption of mitigation-oriented agricultural practices often increases initial costs for farmers. Climate-smart techniques such as no-tillage or precision fertilization require new equipment and technology (Sokal, K. & Kachel, M.2025; Kazimierczuk, K. et all., 2023). Similarly, practices such as organic fertilization or composting initially impose higher labor and logistical costs (Ağaçayak, T., Öztürk, L., 2017). If carbon pricing mechanisms are extended to agriculture, emission-intensive producers may also face direct financial burdens.

2.3. Pressure on International Competitiveness and Trade

The growing global emphasis on emission reduction introduces new rules and standards in international trade. Carbon footprint-based taxes or trade restrictions could negatively affect exports from emission-intensive producers. Countries that delay the shift toward sustainable, low-carbon agriculture risk exclusion from global value chains. Moreover, shifting consumer preferences toward environmentally friendly products create additional transformation pressure on producers.

3. Key Challenges

Managing the economic impacts of GHG emissions and achieving mitigation targets involves a number of structural challenges.

3.1. Technology Adoption and Knowledge Gaps

Although climate-smart agriculture (CSA), regenerative agriculture, and digital solutions offer significant mitigation potential (Kazimierczuk, K. et all., 2023), widespread adoption remains limited. Small-scale farmers in particular face barriers such as high upfront costs, lack of knowledge, and insufficient access to advisory services (Sokal, K. & Kachel, M.2025).

3.2. Financing and Support Mechanisms

Existing agricultural subsidies are counterproductive. They are typically structured to prioritize productivity, which, as Sokal and Kachel (2025) note, inadvertently encourages higher emissions. To resolve this policy misalignment, these government supports must be fundamentally redesigned to instead reward environmental sustainability and lower-impact farming practices. The financial gap is worsened by the limited involvement of the private sector. Private investment remains limited because of genuine and perceived high risk perceptions associated with sustainable farming practices or the necessary technological adoption. This lack of private capital further exacerbates financial constraints, leaving the sector without the diverse funding streams needed for a rapid and effective transition.

In essence, the move to a greener agricultural system requires a dual-pronged financial solution: reforming public finance (subsidies) to incentivize the right behavior, and de-risking the sector to unlock the necessary private investment for widespread, systemic change.

3.3. Policy Alignment and Governance Gaps

Policy integration is a critical factor in achieving effective climate change mitigation within the agricultural sector. The current challenge stems from the fact that crucial policy areas—namely agriculture, environment, energy, and trade—are not adequately coordinated, thereby weakening the overall effectiveness of mitigation strategies.

This policy fragmentation complicates the essential, yet demanding, governance challenge of simultaneously achieving three key, often competing, outcomes: emission reduction, guaranteeing food security, and maintaining farm income stability.

Furthermore, successful agricultural policy must fully embrace vital environmental dimensions that are currently underdeveloped or absent in policymaking. These include the crucial aspects of land use, biodiversity, and water management, which, as highlighted by the World Wildlife Fund (n.d.), are not yet fully integrated into agricultural planning.

4. Policy Responses and Solutions

4.1. Climate-Smart Agriculture and Promotion of Sustainable Practices
This passage outlines the core elements of Climate-Smart Agriculture (CSA) and the specific policy actions needed to promote its adoption, focusing on research, education, and financial support.

CSA is defined by its triple-win objective (Kazimierczuk, K. et al., 2023):

1. Enhance Productivity: Sustainably increase farm output and incomes.
2. Strengthen Climate Resilience: Help farmers adapt to climate change impacts, such as drought or extreme weather.
3. Reduce Emissions: Lower or sequester Greenhouse Gas (GHG) emissions from the agricultural sector.

To facilitate the widespread adoption of these practices, policymakers should focus on the following three integrated areas:

R&D and Extension: The Innovation Engine

Policymakers must invest heavily in Research and Development (R&D) to generate the necessary technological solutions. This includes developing:

- Low-Emission and Climate-Resilient Crop Varieties: Breeding and genetic research to create crops that thrive in new climate conditions while requiring fewer high-emission inputs.
- Locally Adapted Technologies: Focusing innovation on solutions suitable for specific regional climates, soil types, and farming systems.

Training and Advisory Services: Building Capacity

Farmers need the knowledge and skills to implement complex CSA techniques. This requires providing continuous capacity-building through:

- Training and Advisory Services: Robust and accessible extension programs that offer guidance on the best climate-smart practices for local conditions.

Financial Incentives: Driving Adoption

Policy must use financial incentives to de-risk the transition and encourage farmers to adopt more sustainable, low-emission practices (Ağaçayak, T., Öztürk, L., 2017; Sokal, K. & Kachel, M., 2025). Key practices to be supported include:

- Regenerative Agriculture: Rewarding practices that restore soil health and increase carbon sequestration (e.g., cover cropping, reduced tillage).
- Precision Fertilization: Using technology to optimize nutrient application, reducing costly and polluting fertilizer runoff and nitrous oxide emissions.
- Composting: Supporting the use of organic waste to enrich soil and reduce methane emissions from manure storage.
- Efficient Irrigation: Subsidizing or supporting systems that minimize water waste and energy use.
- Energy-Saving Equipment: Providing incentives for the adoption of efficient machinery and on-farm renewable energy sources.

The EU’s Common Agricultural Policy (CAP) is cited as a leading example of a large-scale policy framework that is actively being redesigned to direct funds toward these environmental and climate-friendly outcomes.

4.2. Carbon Pricing and Market-Based Mechanisms

- Carbon Pricing/Trading: Assigning a carbon price to agricultural emissions encourages transitions toward lower-emission alternatives.
- Carbon Farming and Sequestration Payments: Compensating farmers for carbon sequestration through practices such as reduced tillage or agroforestry could transform agriculture into a net carbon sink (Kazimierczuk, K. et all., 2023).

4.3. International Cooperation and Trade Standards

- Sustainability Certification Systems: Extending transparent, measurable sustainability standards to agricultural markets rewards low-carbon producers.
- Just Transition Support: International financing and technology transfer mechanisms should assist developing countries in agricultural decarbonization.

5. Conclusion

This concluding passage summarizes the economic imperative for transforming agriculture and emphasizes the integrated policy approach required to navigate the sector's dual burden.

The Dual Economic Burden of Agriculture

The agricultural sector faces a severe dual burden, simultaneously grappling with the consequences of climate change and the financial requirements of mitigation:

1. Exposure to Climate Shocks: The sector is highly exposed to climate shocks, which directly leads to productivity losses (e.g., due to droughts, floods, or extreme heat). This is an immediate economic impact that threatens food supply.
2. Policy-Related Mitigation Costs: The sector is also required to reduce its emissions, necessitating significant policy-related mitigation costs for new technologies, equipment, and practice changes.

Overcoming this dual financial and environmental pressure demands a comprehensive and unified policy response.

The Call for an Integrated Policy Framework

The text asserts that navigating this challenge calls for an integrated policy framework built on three pillars:

- Promote Climate-Smart Agriculture (CSA): Policy must actively support practices that simultaneously enhance productivity, build resilience, and reduce emissions.
- Ensure Access to Financing: As noted earlier, substantial financing is required. Policy must reduce risk and unlock both public and private capital.
- Align Agricultural, Environmental, and Economic Policies: This is the core governance solution—breaking down policy silos to ensure that all sectoral rules (from subsidies to trade) work in harmony toward climate goals.

Agriculture as a Central Pillar of Climate Action

Ultimately, achieving a sustainable future requires a fundamental shift in perception: acknowledging agriculture not only as a source of food, but also as a central pillar in climate action.

This necessary transformation involves a combination of elements:

- Technological Innovation (R&D for low-emission crops and practices).
- Farmer Training (advisory services and capacity building).
- Market Mechanisms (financial incentives and redesigned subsidies).

The transformation allows no room for error because the stakes are too high. Failure to integrate and act decisively will mean that the rising economic costs will continue to threaten both food security and global development. The economic security of the food system is now directly tied to its environmental sustainability.

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