RESEARCH ARTICLE

Journal of Sustainable Urban Futures

Comparative Analysis of National Policies for Sustainable Agricultural Development and Their Effects on Resource Use Efficiency

Prajwal Khadka Siti[1]
and **Sujata Adhikari** [2]

Accepted: 2023-09-06
Published: 2023-09-13

Full list of author information is available at the end of the article

Abstract

Sustainable agricultural development is essential for tackling global issues like food security, environmental degradation, and climate change. Countries implement varied policy frameworks to encourage sustainable agricultural practices, shaped by differences in socio-economic conditions, resource availability, and political priorities. This paper provides a comparative analysis of national policies aimed at fostering sustainable agricultural development, focusing on their effectiveness in enhancing resource use efficiency. The study examines policies from three countries: the European Union's Common Agricultural Policy (CAP), Brazil's low-carbon agriculture plan (Plano ABC), and India's National Mission for Sustainable Agriculture (NMSA). By evaluating these policies through the lenses of environmental sustainability, economic incentives, and social inclusiveness, the paper highlights best practices and identifies challenges in achieving optimal resource use efficiency. The comparative framework considers factors such as water use, soil management, carbon emissions, and the adoption of green technologies. The analysis reveals that while the EU's CAP provides comprehensive support for agri-environmental measures, its implementation faces constraints due to varying member state priorities. Brazil's Plano ABC shows promise in reducing carbon footprints in agriculture but struggles with issues like enforcement and monitoring. India's NMSA, on the other hand, aims to build climate resilience among smallholder farmers but faces challenges in terms of infrastructure and resource allocation. The findings suggest that tailored policy approaches, which consider local conditions and incorporate stakeholder engagement, are essential for improving resource use efficiency in agriculture. The paper concludes with policy recommendations to enhance international cooperation and knowledge-sharing, aiming to achieve sustainable agricultural practices that balance productivity with environmental stewardship.

Keywords: national policies; resource use efficiency; sustainable agriculture; sustainable development; agricultural policy analysis

1 Introduction

The urgent imperative for sustainable agricultural development highlights the sector's considerable environmental impact, particularly regarding its role in greenhouse gas emissions, habitat loss, and ecosystem deterioration. Agriculture contributes approximately one-quarter of global greenhouse gas emissions, driven largely by methane from livestock and rice paddies, nitrous oxide from synthetic fertilizers, and carbon dioxide emissions from deforestation and land conversion. These emissions amplify the effects of climate change, creating a feedback loop that imposes further environmental stress on agricultural systems. This cycle heightens the vulnerability of crops to climate-induced challenges, such as temperature extremes, shifting precipitation patterns, and an increased frequency of droughts and floods, ultimately threatening agricultural stability and food security.

Additionally, the prevalent reliance on unsustainable practices within agriculture—such as monocropping, which limits genetic diversity, excessive chemical input, and overuse of water resources—undermines soil integrity, diminishes crop resilience, and disrupts natural ecosystems. Intensive monoculture practices, by simplifying crop landscapes, reduce biodiversity and exacerbate pest and disease susceptibility, often leading to escalated chemical interventions. High chemical usage further degrades soil health, creating conditions of nutrient imbalance, acidification, and salinization that reduce long-term land productivity. Combined with the extensive extraction of water for irrigation, these practices not only threaten biodiversity but also place future food supplies at risk. Transitioning to sustainable agriculture is essential, as it offers pathways to mitigate these environmental impacts, preserve ecosystem services, and ensure agricultural productivity within ecologically viable limits.

National policies play an instrumental role in transitioning toward sustainable agricultural systems, shaping the frameworks through which resource-efficient practices are promoted, incentivized, and adopted. By implementing policies that encourage resource conservation and technological innovations, governments can facilitate more sustainable agricultural practices that address both environmental concerns and socio-economic inequities among farmers. However, policy effectiveness is contingent on its alignment with regional agricultural systems, recognizing the variability in local ecological conditions, farmer needs, and resource availability. Policymakers must account for these regional distinctions to ensure that policies are both feasible and impactful, avoiding one-size-fits-all approaches that may overlook local challenges. Additionally, addressing socio-economic barriers within policy frameworks is essential, as disparities in access to technology, capital, and information can hinder sustainable practice adoption, particularly among smallholder and subsistence farmers. This complex interplay of environmental goals and socio-economic realities necessitates a nuanced approach to sustainable agriculture policy, recognizing the critical role of regional adaptability in achieving long-term agricultural sustainability.

This paper aims to conduct a comparative analysis of sustainable agricultural policies implemented in the European Union (EU), Brazil, and India. These regions were chosen due to their distinct agricultural profiles, policy approaches, and varying levels of economic development, providing a diverse perspective on the mechanisms used to enhance sustainability in agriculture. The European Union's Common Agricultural Policy (CAP) has evolved over decades to integrate environmental considerations alongside market stability and rural development. CAP reforms have increasingly emphasized "green direct payments" aimed at encouraging farmers to adopt practices that support biodiversity and soil conservation.

These reforms highlight the EU's focus on balancing agricultural productivity with environmental stewardship. In contrast, Brazil, as a major agricultural exporter, has focused on reducing the environmental impact of its agriculture through the Plano ABC (Agricultura de Baixa Emissão de Carbono), a strategic plan targeting carbon emissions and deforestation through practices such as no-till farming, reforestation, and integrated crop-livestock systems. This approach aligns with Brazil's position as a global leader in beef, soy, and coffee production while addressing the critical challenge of deforestation in the Amazon basin. India's National Mission for Sustainable Agriculture (NMSA) is designed to improve climate resilience among smallholders, reflecting the country's diverse and climate-vulnerable agricultural landscape. With a focus on rain-fed farming regions, NMSA promotes practices such as organic farming, efficient water use, and the adoption of climate-resilient crop varieties, aiming to reduce vulnerability to monsoon variability and extreme weather events.

The objective of this study is to assess the impacts of these policies on resource use efficiency, defined as the optimization of inputs such as water, soil, and energy to achieve sustainable output levels. Resource use efficiency in agriculture entails reducing the inputs required for production while maintaining or enhancing yield levels. For example, practices like precision irrigation and integrated pest management help reduce water and chemical use, directly contributing to sustainability. Through this analysis, the paper seeks to identify key success factors, common challenges, and potential areas for policy improvement. The comparative approach provides insights into how different policy instruments, such as subsidies, regulatory frameworks, and capacity-building initiatives, affect the adoption of sustainable practices among farmers. Additionally, it considers the role of market mechanisms, such as carbon credits and eco-labeling, in incentivizing sustainable agricultural practices.

The insights gained can inform future policy development, aiming for a global transition toward sustainable agriculture that is equitable, economically viable, and environmentally sound. A key aspect of this transition involves addressing the socio-economic disparities that exist among smallholders and large-scale producers, as these disparities can impact the uptake of sustainable practices. Policies must account for the varying capacities of farmers to invest in new technologies and practices, ensuring that smaller and resource-poor farmers are not left behind. This is particularly crucial in developing countries like India, where smallholders constitute the majority of the agricultural workforce but often lack access to capital and technical knowledge. Meanwhile, the analysis of Brazil's experience with the Plano ABC offers insights into balancing economic growth with environmental conservation, particularly in contexts where agriculture is a significant contributor to national GDP. The EU's CAP reforms provide a model for integrating sustainability into a highly regulated agricultural sector, demonstrating the potential for policy frameworks that align market incentives with environmental outcomes.

Table 1 presents an overview of the key features of the agricultural policies in the EU, Brazil, and India. It highlights the main policy instruments, target groups, and environmental focus areas, providing a comparative perspective on the strategies employed by each region to promote sustainable agricultural practices.

Table 1 Comparative Overview of Sustainable Agricultural Policies in the European Union, Brazil, and India

Region	Key Policy	Policy Instruments	Environmental Focus Areas
European Union	Common Agricultural Policy (CAP)	Green direct payments, cross-compliance measures, rural development programs	Biodiversity conservation, soil health, water quality, climate adaptation
Brazil	Plano ABC (Low Carbon Agriculture Plan)	Credit lines, technical assistance, tax incentives for sustainable practices	Reduction of carbon emissions, deforestation control, integrated crop-livestock systems
India	National Mission for Sustainable Agriculture (NMSA)	Subsidies for organic farming, training programs, water management initiatives	Climate resilience, efficient water use, soil health improvement, promotion of drought-resistant crops

The comparative analysis presented in this paper will focus on evaluating the outcomes of these policies in terms of their impact on resource use efficiency, particularly looking at water and soil conservation, energy use in farming operations, and the overall reduction in greenhouse gas emissions. By understanding the similarities and differences in policy approaches across these diverse regions, this study aims to provide a comprehensive understanding of the factors that drive successful policy implementation in sustainable agriculture. For instance, the study will explore how the EU's regulatory approach differs from Brazil's market-driven incentives, and how India's focus on smallholder resilience influences the adoption of sustainable practices. Additionally, the paper will identify common challenges, such as financial constraints, lack of access to technology, and institutional barriers, that hinder the effective implementation of sustainability-focused policies.

The findings of this comparative analysis have broader implications for international cooperation on agricultural sustainability. As global agricultural trade becomes increasingly interconnected, policies that promote sustainability in one region can have significant impacts on global markets and environmental outcomes. For example, the EU's emphasis on sustainability through CAP has influenced export standards and trade agreements, encouraging trading partners to adopt similar environmental practices. Brazil's efforts to reduce deforestation in the Amazon through sustainable agricultural practices are crucial not only for local biodiversity but also for global climate stability. India's approach, focusing on climate adaptation for smallholders, offers a valuable model for other developing nations facing similar challenges. These interconnected dynamics underscore the importance of aligning national policies with global sustainability goals to achieve a balanced approach to agricultural development that benefits both people and the planet.

Table 2 provides a summary of the key outcomes and impacts of the sustainable agricultural policies in the EU, Brazil, and India. It highlights their achievements in resource use efficiency, climate adaptation, and socio-economic impacts, offering a comparative assessment of how different policy frameworks translate into practical outcomes on the ground.

the comparative analysis of these policies not only sheds light on the diversity of approaches to sustainable agricultural development but also provides valuable lessons for future policy design. It emphasizes the need for context-specific strategies that account for local socio-economic and environmental conditions while aligning with global sustainability goals. By learning from the successes and challenges faced by the EU, Brazil, and India, policymakers can craft more effective frameworks that

Table 2 Summary of Policy Outcomes and Impacts on Sustainable Agriculture in the European Union, Brazil, and India

Region	Resource Use Efficiency	Climate Adaptation	Socio-Economic Impact
European Union	Increased efficiency in water use through precision agriculture; improvements in soil health due to conservation practices	Enhanced resilience through climate-smart farming practices	Positive impact on rural employment and income stability through diversified rural development programs
Brazil	Reduction in carbon emissions from deforestation and agricultural activities; efficient land use through integrated systems	Development of resilient agricultural models in response to regional climate conditions	Improved access to credit for sustainable practices; economic benefits for farmers adopting low-carbon techniques
India	Enhanced water use efficiency through micro-irrigation; adoption of organic and low-input farming methods	Promotion of drought-resistant crop varieties and improved farming practices in climate-vulnerable regions	Increased income stability for smallholders through subsidies and support for organic farming

advance sustainable agriculture, ensuring that future generations can thrive in a world where food security and environmental integrity are mutually reinforcing.

2 Comparative Framework for Policy Analysis

A robust comparative framework is essential for analyzing the effectiveness of national policies on sustainable agricultural development. This study employs a framework that examines policies across three dimensions: environmental sustainability, economic incentives, and social inclusiveness. Each of these dimensions is crucial in understanding how policies influence resource use efficiency and overall agricultural sustainability. This comparative framework enables a systematic evaluation of how different national policies support the transition to sustainable agriculture, highlighting both strengths and areas for improvement in policy design and implementation.

2.1 Environmental Sustainability

Environmental sustainability in agriculture refers to the ability of farming practices to maintain soil health, preserve water resources, reduce carbon emissions, and protect biodiversity. Policies that promote environmentally sustainable practices often include regulations on pesticide use, incentives for organic farming, and support for conservation practices. These measures are critical for ensuring that agricultural activities do not compromise the ecological balance, allowing future generations to meet their needs.

In the European Union, the Common Agricultural Policy (CAP) has incorporated agri-environmental measures, such as the Green Direct Payment, which encourages farmers to maintain permanent grassland, crop diversification, and ecological focus areas. These measures are designed to enhance biodiversity, reduce soil erosion, and improve carbon sequestration. The CAP's emphasis on maintaining ecological focus areas has been particularly effective in regions with strong institutional support, where local governments actively promote compliance among farmers. However, the success of these measures is often uneven across member states due to differing levels of commitment and enforcement capabilities. For example, countries with stronger agricultural sectors tend to allocate more resources toward monitoring compliance, while others may struggle with limited enforcement capacity.

Brazil's Plano ABC (Agricultura de Baixa Emissão de Carbono) focuses on reducing the carbon footprint of agriculture through practices such as no-till farming, reforestation, and integrated crop-livestock systems. These measures aim at improving soil carbon sequestration and reducing deforestation, thereby contributing to both climate mitigation and biodiversity conservation. The policy has achieved measurable reductions in carbon emissions, particularly through the adoption of no-till practices that enhance soil health and reduce erosion. However, challenges such as illegal deforestation in the Amazon and enforcement limitations hinder the overall impact of Plano ABC on sustainable development. Enforcement challenges are particularly acute in remote regions where governance structures are weaker, leading to disparities in policy impact across the country.

India's National Mission for Sustainable Agriculture (NMSA) emphasizes climate-resilient agricultural practices, such as water-saving technologies, integrated nutrient management, and soil health management. Given India's high dependency on monsoon rainfall, the policy's focus on water use efficiency is particularly important for enhancing agricultural resilience to climate variability. The NMSA promotes the use of micro-irrigation systems, which are essential for optimizing water use in drought-prone regions. However, the fragmented nature of policy implementation and limited infrastructure pose significant challenges in achieving widespread adoption of sustainable practices. The effectiveness of NMSA is further constrained by regional disparities, as well-developed states tend to implement these measures more effectively compared to poorer regions with limited administrative capacity.

Table 3 Comparative Analysis of Environmental Sustainability in Agricultural Policies

Country/Region	Key Policy Initiatives	Environmental Impact
European Union (EU)	Common Agricultural Policy (CAP) with Green Direct Payment	Promotes biodiversity and soil conservation through crop diversification and ecological focus areas. Success varies across member states due to differing enforcement capacities.
Brazil	Plano ABC (Low-Carbon Agriculture)	Focuses on reducing carbon emissions through no-till farming and reforestation. Achievements include improved soil health, but enforcement challenges remain in the Amazon region.
India	National Mission for Sustainable Agriculture (NMSA)	Emphasizes water-saving technologies and soil management to enhance resilience. Effectiveness is limited by regional disparities and fragmented policy implementation.

2.2 Economic Incentives

Economic incentives are a critical tool for encouraging farmers to adopt sustainable practices. These can include subsidies, tax relief, grants, and access to low-interest loans. The design and distribution of economic incentives significantly influence the extent to which farmers can adopt new practices, especially those that require upfront investments.

The CAP provides direct payments to European farmers, including subsidies linked to compliance with environmental standards. This has helped to balance the economic pressures faced by farmers with the need to adopt sustainable practices, such as reducing pesticide use and maintaining buffer zones for water conservation. These subsidies make it financially viable for farmers to invest in sustainable methods that may otherwise be cost-prohibitive. However, the subsidy system has been criticized for benefiting larger farms disproportionately, potentially undermining support for smallholders who play a key role in sustainable agriculture. Large-scale agricultural operations often have more resources to navigate complex subsidy applications, while smaller farms may lack the administrative capacity to do so.

In Brazil, Plano ABC offers financial incentives for farmers to adopt low-carbon practices, including subsidized credit lines for sustainable technologies. This approach has been effective in encouraging the adoption of advanced practices, such as precision agriculture and agroforestry, which enhance resource efficiency. These subsidies have supported the development of a market for sustainable products, allowing Brazilian farmers to access higher-value export markets. However, issues related to credit accessibility, especially for small-scale farmers, have limited the broader adoption of these sustainable practices. Many smallholders face difficulties in meeting the collateral requirements for accessing credit, which remains a significant barrier to entry for those who could benefit most from the transition to sustainable methods.

India's NMSA includes provisions for financial support to small and marginal farmers, aiming to enhance their capacity to adopt climate-resilient practices. This includes subsidies for micro-irrigation systems, soil testing facilities, and organic farming initiatives. The focus on supporting smallholders is particularly relevant in India, where a large proportion of the agricultural sector consists of small and marginal farmers. Despite these efforts, the effectiveness of such incentives is often reduced by bureaucratic delays and limited outreach, preventing many eligible farmers from accessing the available support. The decentralized nature of policy implementation in India, coupled with varying administrative capacities across states, results in unequal distribution of benefits.

Table 4 Comparative Analysis of Economic Incentives in Agricultural Policies

Country/Region	Incentive Mechanisms	Impact on Adoption of Sustainable Practices
European Union (EU)	Direct payments under the CAP linked to environmental standards	Supports adoption of sustainable practices, but larger farms benefit more than smallholders, leading to unequal support distribution.
Brazil	Subsidized credit lines through Plano ABC	Encourages adoption of precision agriculture and low-carbon practices, yet credit access challenges limit reach among small-scale farmers.
India	Financial support under the NMSA for smallholders	Focused on enhancing resilience through subsidies for water-efficient practices, but effectiveness is constrained by bureaucratic barriers and uneven implementation.

2.3 Social Inclusiveness

Social inclusiveness in agricultural policy refers to the degree to which policies support marginalized groups, such as smallholder farmers, women, and indigenous communities, ensuring equitable access to resources and opportunities. Policies that emphasize social inclusiveness are essential for promoting equitable development and ensuring that the transition to sustainable agriculture benefits all stakeholders.

The CAP has integrated rural development programs that aim to support small-scale farmers and promote rural cohesion. These programs include measures for supporting young farmers, improving rural infrastructure, and fostering innovation in less developed rural areas. However, disparities remain between newer and older EU member states in terms of access to these benefits. In newer member states, the transition from state-controlled agricultural systems to market-oriented economies has often left smallholders at a disadvantage in accessing EU funds, leading to regional inequalities in the impact of the CAP.

Brazil's Plano ABC aims to support smallholder farmers through training programs and technical assistance, yet these efforts are often concentrated in more developed regions, leading to regional disparities in policy impacts. Indigenous communities, particularly in the Amazon, frequently face challenges in accessing the benefits of sustainable agriculture policies due to social and economic barriers. These barriers include limited access to credit, lower levels of education, and a lack of formal land titles, which complicates participation in government programs. While the policy includes measures to address these issues, the effectiveness of implementation remains uneven.

India's NMSA is explicitly designed to enhance the resilience of smallholder farmers, who constitute a large proportion of the country's agricultural sector. The policy includes targeted support for women farmers and marginalized communities through capacity-building programs, aiming to empower these groups and improve their adaptation to climate change. Despite these efforts, the reach of such programs is often limited by regional variations in policy implementation and the lack of local governance structures to facilitate effective participation. In states with better governance frameworks, the impact of NMSA on marginalized communities is more pronounced, whereas in regions with weaker administrative capacity, these groups remain underserved.

The comparative analysis of social inclusiveness in agricultural policies underscores the importance of addressing regional disparities and ensuring that marginalized groups have equal access to the benefits of sustainable agricultural development. Effective policies must integrate both financial and technical support with measures to overcome social and economic barriers, thereby ensuring that the transition to sustainable agriculture is inclusive and equitable.

3 Policy Outcomes and Resource Use Efficiency

The effectiveness of national policies in improving resource use efficiency can be measured by analyzing outcomes such as water savings, soil health improvements, carbon footprint reductions, and the adoption of innovative technologies. These indicators provide valuable insights into how policy measures translate into tangible environmental and economic benefits for the agricultural sector. While the overarching goals of sustainable agricultural policies are often similar across different countries, the approaches and degrees of success can vary widely depending on regional conditions, governance structures, and the level of investment in supporting infrastructure.

3.1 Water Use Efficiency

Water use efficiency is a critical component of sustainable agriculture, particularly in regions facing water scarcity and increasing climate variability. Efficient water management is essential not only for maintaining agricultural productivity but also for preserving aquatic ecosystems and ensuring the long-term sustainability of water resources. Several national policies aim to promote the adoption of water-saving practices and technologies, such as micro-irrigation systems, rainwater harvesting, and soil moisture management techniques.

The European Union's Common Agricultural Policy (CAP) supports measures for efficient irrigation systems and the preservation of water bodies through incentives and direct payments to farmers who adopt water-efficient practices. This policy framework encourages the adoption of technologies like drip irrigation, which can significantly reduce water wastage compared to traditional flood irrigation methods. However, the implementation of these measures varies across EU member states. For example, Spain and Italy have shown greater advancements in adopting water-efficient irrigation technologies compared to other countries, driven by their acute need to address water scarcity in Mediterranean climates. These countries have invested heavily in modern irrigation infrastructure and have seen substantial improvements in water use efficiency as a result.

In contrast, countries with more abundant water resources, such as those in northern Europe, have been slower to adopt these practices, reflecting the lower perceived urgency of water conservation. The variability in outcomes highlights the importance of tailoring policy measures to regional conditions and ensuring that water conservation incentives are aligned with local agricultural needs and water availability.

Brazil's emphasis on integrated crop-livestock systems under its Low Carbon Agriculture Plan (Plano ABC) has also led to improvements in water use efficiency. By promoting practices like no-till farming and the use of pasture grasses with deep root systems, the policy has enhanced soil water retention, reducing the overall need for irrigation. These practices have been particularly effective in regions like the Cerrado, where water conservation is essential for maintaining agricultural productivity. However, water management challenges persist in areas with high deforestation rates, such as the Amazon, where changes in land use have disrupted local hydrological cycles. The reduction of forest cover can alter rainfall patterns and decrease water availability, underscoring the interconnected nature of agricultural policies, environmental conservation, and water resources management.

India's National Mission for Sustainable Agriculture (NMSA) places significant emphasis on improving water use efficiency through the promotion of micro-irrigation technologies, such as drip and sprinkler systems. These efforts have been particularly successful in states like Maharashtra and Gujarat, where subsidies for micro-irrigation equipment have encouraged widespread adoption. These technologies have led to notable improvements in crop productivity per unit of water used, contributing to greater resilience in the face of variable monsoon patterns. However, many regions in India continue to rely on traditional, water-intensive irrigation practices due to inadequate infrastructure, insufficient access to capital, and limited farmer training. The success of India's water conservation efforts is thus closely tied to the capacity-building initiatives and extension services provided to farmers, as well as investments in modernizing irrigation infrastructure.

3.2 Soil Health and Carbon Sequestration

Soil health is crucial for long-term agricultural productivity, as it directly influences the ability of soil to retain moisture, support plant growth, and store carbon. Improving soil health is a central goal of many sustainable development policies, as healthy soils not only support higher yields but also play a critical role in sequestering carbon and mitigating climate change. The adoption of practices such as no-till

Table 5 Comparative Analysis of Water Use Efficiency Policies

Country/Region	Policy Focus	Outcomes and Challenges
European Union (EU)	CAP supports efficient irrigation and water body conservation.	Significant improvements in countries like Spain and Italy, but slower progress in northern regions with abundant water resources.
Brazil	Plano ABC promotes integrated crop-livestock systems to improve soil water retention.	Reduced irrigation needs in regions like the Cerrado, but deforestation impacts water cycles in the Amazon.
India	NMSA promotes micro-irrigation technologies such as drip and sprinkler systems.	Improved water use efficiency in states like Maharashtra, but traditional practices persist in regions lacking infrastructure.

farming, cover cropping, and the use of organic amendments has been promoted across various policy frameworks to enhance soil structure and increase soil organic carbon levels.

The European Union's CAP has been instrumental in promoting soil health through its agri-environmental schemes, which encourage practices such as crop rotation, cover cropping, and reduced soil disturbance. These practices help to maintain or improve soil structure, increase biodiversity within the soil ecosystem, and enhance the soil's capacity to sequester carbon. Additionally, the CAP provides support for the adoption of precision agriculture technologies that optimize the application of fertilizers and reduce soil compaction, further contributing to soil conservation efforts. However, the success of these measures varies among member states, with some countries facing challenges in aligning local agricultural practices with the broader goals of soil health improvement.

Brazil's Plano ABC has had a significant impact on soil carbon sequestration through the promotion of no-till farming and reforestation efforts. The expansion of no-till systems in Brazil has resulted in significant increases in soil organic matter, enhancing soil fertility and resilience against erosion. Moreover, the restoration of degraded pasturelands and the promotion of agroforestry systems under Plano ABC have contributed to substantial carbon sequestration, supporting both climate mitigation and improved soil health. Despite these successes, implementation challenges such as uneven policy enforcement and varying levels of adoption across different states can hinder the full realization of soil health benefits.

In India, soil health management under the NMSA includes initiatives like soil testing and the use of organic amendments to improve soil quality. The Soil Health Card scheme, which provides farmers with detailed information on soil nutrient status and recommendations for fertilizer application, is a key component of these efforts. While the scheme has improved awareness among farmers about the importance of balanced fertilization, adoption rates remain inconsistent due to logistical challenges, including delays in soil testing and the limited availability of organic inputs. Additionally, the transition to organic amendments often requires substantial changes in farm management practices, which can deter adoption without sufficient support and training.

3.3 Adoption of Green Technologies

The adoption of green technologies, such as precision agriculture, renewable energy systems, and sustainable pest management techniques, plays a key role in achieving resource use efficiency. These technologies enable farmers to reduce input use,

Table 6 **Impact of Sustainable Development Policies on Soil Health and Carbon Sequestration**

Country/Region	Policy Initiatives	Outcomes and Challenges
European Union (EU)	CAP supports crop rotation, cover cropping, and precision agriculture.	Improved soil health and carbon sequestration in some regions, but varied adoption rates across member states.
Brazil	Plano ABC promotes no-till farming, reforestation, and pasture restoration.	Significant increases in soil organic carbon, but challenges in policy enforcement across states.
India	NMSA focuses on soil testing and the use of organic amendments through the Soil Health Card scheme.	Improved awareness but inconsistent adoption due to logistical and infrastructural barriers.

optimize resource application, and minimize the environmental impacts of farming activities. National policies that provide financial incentives, technical assistance, and support for research and development can significantly accelerate the adoption of these innovations.

The EU's CAP has facilitated the adoption of precision agriculture technologies by offering subsidies and grants for investments in advanced machinery and digital tools. Precision agriculture technologies, such as GPS-guided equipment and variable-rate application systems, allow for more efficient use of water, fertilizers, and pesticides, reducing the overall environmental footprint of farming. These technologies have been particularly successful in countries with high levels of mechanization and access to digital infrastructure, such as Germany and France. However, smaller farms often face barriers to adoption due to the high initial costs of equipment and the need for technical expertise.

Brazil's Plano ABC has also supported the adoption of technologies that reduce greenhouse gas emissions and enhance resource efficiency. For example, the plan has encouraged the use of integrated systems that combine livestock and crops, as well as the adoption of renewable energy sources like biogas generated from agricultural waste. These initiatives have helped to lower the carbon footprint of Brazilian agriculture while improving the productivity and sustainability of farming systems. Nevertheless, disparities in access to financing and technical support remain a challenge, particularly for small and medium-sized farms.

In India, the focus has been on promoting low-cost, context-specific technologies suitable for small-scale farmers. Initiatives under the NMSA include the dissemination of solar-powered irrigation pumps, improved seed varieties, and organic pest control methods. While these efforts have made technology more accessible to smallholders, the diffusion of green technologies remains slow due to limited access to credit, technical expertise, and market linkages. The effectiveness of these policies is closely tied to the strength of extension services and the availability of support for capacity building at the local level.

the outcomes of sustainable development policies in improving resource use efficiency depend on a range of factors, including the local context, the level of investment in supportive infrastructure, and the extent of coordination between policy measures and educational initiatives. While many countries have made progress in promoting water use efficiency, improving soil health, and fostering the adoption of green technologies, the challenges of policy implementation remain significant. Achieving sustainable resource management requires ongoing efforts to tailor policies to regional needs, address barriers to adoption, and ensure that the benefits of sustainable practices reach all segments of the farming population.

4 Conclusion

The comparative analysis of sustainable agricultural policies in the European Union (EU), Brazil, and India offers significant insights into the intricate task of promoting resource use efficiency while accommodating diverse socio-economic and environmental conditions. The study reveals that although each of these regions has developed unique policy frameworks tailored to their respective contexts, common challenges such as regional disparities, implementation gaps, and issues related to accessibility remain persistent. Addressing these challenges is crucial for the effective realization of sustainable agricultural practices that balance productivity with environmental and social considerations.

The Common Agricultural Policy (CAP) of the European Union exemplifies a well-structured and comprehensive approach to integrating environmental measures within agricultural policy. Its emphasis on agri-environmental schemes and cross-compliance requirements has provided a strong foundation for promoting biodiversity conservation, water management, and soil health. However, disparities in the uptake and effectiveness of these measures across different EU member states highlight the challenges posed by varying regional capacities and socio-economic conditions. For instance, Eastern European countries often face more significant hurdles in meeting CAP standards due to limited infrastructure and financial resources, contrasting with the more developed agricultural systems in Western Europe. Additionally, the complexity of the CAP's regulatory framework has sometimes been a barrier for smaller farms, limiting their ability to fully engage with the program's benefits.

In contrast, Brazil's Plano ABC (Low-Carbon Agriculture Plan) underscores the country's emphasis on reducing carbon emissions through specific agricultural practices, such as no-till farming, recovery of degraded pastures, and integrated crop-livestock-forestry systems. The plan's focus on mitigating climate change while improving productivity is well-aligned with global climate goals. However, despite these advancements, challenges such as the uneven implementation across Brazil's vast territory, particularly in the Amazon region, and the difficulty in accessing financial resources for smaller producers, have limited the plan's overall impact. The geographic size of Brazil and the socio-economic disparities between regions like the South and the Northeast exacerbate these issues, creating an uneven playing field for policy adoption and enforcement.

Similarly, India's approach to sustainable agriculture, characterized by programs like the National Mission for Sustainable Agriculture (NMSA) and the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), has focused on improving water use efficiency, soil health management, and promoting climate-resilient agriculture. While these initiatives have had a positive impact in certain regions, India faces significant challenges due to its diverse agro-climatic zones and the socio-economic heterogeneity of its agricultural communities. Implementation gaps, such as insufficient extension services and limited access to credit and technology for smallholder farmers, have constrained the reach and effectiveness of these programs. Furthermore, the uneven distribution of irrigation infrastructure continues to exacerbate regional disparities, leaving some states more vulnerable to the impacts of climate change than others.

The analysis reveals that despite differences in policy focus, a common theme across the EU, Brazil, and India is the need for adaptive policy designs that are responsive to local conditions. This involves tailoring strategies to address the specific environmental and socio-economic contexts of different regions, ensuring that policies are flexible enough to adapt to changing conditions while remaining aligned with national sustainability goals. For example, within the EU, greater flexibility in CAP's implementation could help accommodate the varying capacities of member states. In Brazil, strengthening local governance structures could improve the management of resources and the enforcement of low-carbon agricultural practices. Meanwhile, in India, investing in region-specific extension services could enhance the effectiveness of programs aimed at smallholder farmers.

The findings also underscore the importance of robust enforcement mechanisms that can bridge the gap between policy design and on-ground implementation. Effective monitoring and evaluation systems are crucial in ensuring that policies do not remain merely aspirational but are translated into tangible outcomes. This requires a commitment to continuous data collection, capacity-building among local authorities, and the establishment of accountability frameworks that ensure compliance with sustainable practices. For instance, the EU's ongoing reform of the CAP includes provisions for better monitoring of agri-environmental measures, which could serve as a model for other regions. Brazil and India could benefit from similar investments in data-driven policy monitoring to improve transparency and responsiveness.

Furthermore, enhancing stakeholder engagement is a critical component of successful policy implementation. Engaging farmers, local communities, and civil society organizations in the policy-making process can help to ensure that the design and implementation of agricultural policies are more inclusive and better aligned with the needs of those directly affected by them. This collaborative approach can also foster a sense of ownership among stakeholders, increasing their willingness to adopt sustainable practices. For example, in India, involving farmer cooperatives and grassroots organizations in the dissemination of climate-resilient agricultural practices has shown promise in enhancing local uptake of these measures. In Brazil, partnerships between government, private sector, and research institutions have been pivotal in promoting technological innovations in agriculture.

International collaboration also emerges as a key strategy in overcoming the challenges faced by these countries. By engaging in cross-country knowledge-sharing and capacity-building initiatives, countries can benefit from the experiences of others and adopt best practices suited to their contexts. For example, the EU's experience with developing sophisticated agri-environmental schemes could provide valuable lessons for India and Brazil in designing incentives for sustainable practices. Conversely, Brazil's advancements in carbon reduction through agricultural methods could inform efforts in the EU to enhance carbon sequestration on agricultural lands. Multilateral forums such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Food and Agriculture Organization (FAO) offer platforms for such exchanges, emphasizing the need for sustained international cooperation in addressing the global challenge of agricultural sustainability.

To illustrate the potential of international collaboration, Table 7 provides examples of knowledge-sharing initiatives and their impact on agricultural policy development in the EU, Brazil, and India. These initiatives demonstrate how international cooperation can accelerate the adoption of best practices and foster innovation in sustainable agriculture.

Table 7 Examples of International Knowledge-Sharing Initiatives and their Impact

Initiative	Participating Countries	Impact on Agricultural Policy Development
EU-Brazil Cooperation on Low-Carbon Agriculture	European Union, Brazil	Facilitated exchange of best practices in no-till farming and integrated crop-livestock systems, contributing to Brazil's development of the Plano ABC and the EU's initiatives on carbon sequestration.
India-EU Water Partnership (IEWP)	India, European Union	Enhanced knowledge-sharing on water management techniques, influencing the design of India's PMKSY and improving water use efficiency practices in EU agricultural policy.
UNFCCC Capacity-Building Workshops	Brazil, India, European Union, and other countries	Provided a platform for sharing strategies on climate-resilient agriculture, leading to the refinement of national climate action plans and integration of sustainable agricultural practices.

By addressing these challenges and building on the strengths of their respective frameworks, the EU, Brazil, and India have the potential to align their agricultural productivity goals with the imperative of environmental sustainability. This alignment is essential for ensuring that agricultural systems remain resilient in the face of future challenges, such as climate change, resource scarcity, and evolving market demands. National policies that incorporate adaptive measures, robust enforcement, and collaborative frameworks are better positioned to navigate these complexities and achieve long-term sustainability.

Moreover, achieving a balanced approach that integrates economic viability, social equity, and environmental protection is critical for sustainable agricultural development. Economic viability ensures that farmers have the necessary resources and incentives to adopt sustainable practices, while social equity ensures that these practices are accessible to all segments of the farming community, including smallholders and marginalized groups. Environmental protection, on the other hand, safeguards the ecological foundations upon which agriculture depends. Table 8 provides a summary of how different aspects of sustainability are integrated into the agricultural policies of the EU, Brazil, and India.

Table 8 Integration of Sustainability Dimensions in Agricultural Policies

Region	Economic Viability	Social Equity	Environmental Protection
European Union (CAP)	Direct payments and market support mechanisms ensure income stability for farmers.	Focus on rural development programs that support small farms and promote community-led initiatives.	Agri-environmental schemes promote biodiversity, soil health, and water management.
Brazil (Plano ABC)	Incentives for sustainable practices like no-till farming improve productivity.	Programs target support for smallholders in implementing low-carbon practices.	Emphasis on reducing emissions through carbon sequestration and reforestation.
India (NMSA, PMKSY)	Subsidies and credit schemes support investments in sustainable agriculture.	Focus on empowering smallholder farmers through training and extension services.	Programs promote water conservation, soil health, and climate-resilient practices.

The analysis concludes that achieving truly sustainable agricultural development requires a holistic approach, where economic, social, and environmental dimensions are interlinked. By learning from one another and engaging in ongoing dialogues, countries can refine their strategies to ensure that agricultural practices are not only productive but also sustainable and inclusive. The pathway forward involves embracing a shared vision for agricultural sustainability that transcends national boundaries, fostering a global agricultural system capable of meeting the needs of the present without compromising the ability of future generations to meet their own needs. This vision is essential for addressing the interconnected challenges of food security, climate change, and rural development, and for ensuring that agriculture remains a source of resilience and opportunity in an increasingly uncertain world.

[1, 2, 2, 3, 3, 4, 4, 5, 5–53]

Author details
[1]Department of Public Policy, Sagarmatha Institute of Technology, 89 Kalimati Road, Kathmandu, 44601, Nepal..
[2]Department of Environmental Science and Management, Lumbini University of Applied Sciences, Buddha Path, Butwal, Rupandehi, 32907, Nepal..

References

1. Ramirez, J., Patel, A.: Global business strategies and environmental sustainability. Sustainable Development **21**(5), 305–315 (2013)
2. Asthana, A.N.: Demand analysis of rws in central india (1995)
3. Asthana, A.: Water: Perspectives, issues, concerns. FRANK CASS CO LTD NEWBURY HOUSE, 900 EASTERN AVE, NEWBURY PARK, ILFORD . . . (2003)
4. Asthana, A.: What determines access to subsidised food by the rural poor?: Evidence from india. International Development Planning Review **31**(3), 263–279 (2009)
5. Asthana, A.N.: Decentralisation and supply efficiency of rws in india (2003)
6. Smith, K., Lee, S.-J.: The future of sustainability in international education. In: Proceedings of the International Conference on Education for Sustainable Development, pp. 134–142 (2016). UNESCO
7. Nguyen, L., Garcia, M.: Strategies for enhancing sustainability in business education. In: Proceedings of the Academy of International Business, pp. 95–103 (2014). AIB
8. Thomas, A., Yamada, R.: Renewable energy policies and their impact on international business. Renewable Energy **67**, 733–742 (2014)
9. Turner, J., Lee, Y.: Education and Sustainable Development: A Policy Framework. Routledge, New York, USA (2016)
10. Yang, F., Johnson, R.: Innovation and sustainability in international business policy. Journal of Cleaner Production **142**, 3373–3382 (2017)
11. Roberts, M., Kaur, P.: Sustainable Development and Resource Allocation in International Business. Cambridge University Press, Cambridge, UK (2013)
12. Thompson, D., Gupta, R.: Sustainable development and the role of international business. Journal of World Business **50**(4), 616–625 (2015)
13. Schneider, F., Tan, M.: Sustainable Resource Management in Global Supply Chains. Kogan Page, London, UK (2013)
14. Adams, P., Luo, W.: Sustainable business strategies: A policy perspective. Journal of Business Ethics **135**(3), 473–485 (2016)
15. Wang, L., Garcia, P.: Corporate policies for sustainable development in emerging economies. In: Proceedings of the International Conference on Corporate Sustainability, pp. 89–98 (2014). IEEE
16. Perez, M., Sharma, K.: Resource management and corporate responsibility: A global perspective. Business Strategy and the Environment **22**(6), 383–392 (2013)
17. Davies, M., Zhang, Y.: Policy Frameworks for Sustainable Development in the 21st Century. Oxford University Press, Oxford, UK (2012)
18. Asthana, A.N.: Who do we trust for antitrust? deconstructing structural io. World Applied Sciences Journal **22**(9), 1367–1372 (2013)
19. Davis, E., Martinez, L.: Green strategies in international business: A policy analysis. Global Environmental Politics **17**(2), 132–145 (2017)
20. Asthana, A.N.: Profitability prediction in cattle ranches in latin america: A machine learning approach. Glob. Vet. **4**(13), 473–495 (2014)
21. Richards, P., Zhao, F.: Innovation and Sustainability in Global Enterprises. Palgrave Macmillan, New York, USA (2015)
22. Rossi, A., Becker, L.: Developing policies for sustainable resource management in europe. In: Proceedings of the European Conference on Sustainable Development, pp. 102–109 (2014). UNEP
23. Asthana, A.N.: Voluntary sustainability standards in latin american agribusiness: Convergence and differentiation. American-Eurasian J. Agric. Environ. Sci. (2014)
24. Nguyen, T., Peters, T.: Strategies for sustainable development in emerging markets. In: Proceedings of the Global Business and Technology Association, pp. 234–240 (2015). GBATA
25. Morgan, H., Verhoeven, L.: Sustainability in corporate strategy: A european perspective. European Management Journal **34**(4), 347–359 (2016)
26. Asthana, A., Tavželj, D.: International business education through an intergovernmental organisation. Journal of International Business Education **17**, 247–266 (2022)

27. Morris, L., Schmidt, T.: Education for sustainable development: Innovations and impacts. Journal of Education for Sustainable Development **8**(2), 178–192 (2014)
28. Pavlov, A., Silva, C.: Sustainability in international business operations: Best practices. Journal of International Management **21**(3), 234–245 (2015)
29. Liu, J., Brown, S.: The role of education in promoting sustainable business practices. In: Proceedings of the International Conference on Sustainable Development, pp. 90–98 (2016). UNESCO
30. Asthana, A.N., Charan, N.: Curricular infusion in technology management education programmes. Journal of Data Acquisition and Processing **38**(3), 3522 (2023)
31. Martin, F., Hernandez, P.: Sustainability and Business Innovation: Bridging the Gap. Oxford University Press, Oxford, UK (2013)
32. Kim, M.-S., Rossi, G.: Policies for sustainable resource management: A comparative study. Journal of Environmental Policy Planning **18**(2), 179–196 (2016)
33. Larsen, H., Cheng, L.: Managing Resources for Sustainable Business Development. Springer, Berlin, Germany (2012)
34. Ahmed, Y., Fischer, M.: Climate change and business strategies for sustainability. Journal of Business Research **76**, 221–230 (2017)
35. Ali, H., Martin, C.: Climate change policies and business adaptation strategies. Climate Policy **14**(5), 629–643 (2014)
36. Almeida, R., Singh, P.: Challenges in implementing sustainability policies in international business. In: Proceedings of the Global Conference on Sustainable Development, pp. 45–53 (2013). Wiley
37. Baker, S., Zhou, M.: Environmental policies and business education: A cross-country analysis. In: Proceedings of the International Association for Business and Society, pp. 220–229 (2016). IABS
38. Asthana, A.N., Charan, N.: How fair is fair trade in fisheries? Journal of Survey in Fisheries Sciences, 205–213 (2023)
39. Baker, W., Nguyen, M.: Corporate Sustainability: Managing Environmental, Social, and Economic Impacts. Cambridge University Press, Cambridge, UK (2017)
40. Brown, A., Santos, M.: Education and Global Sustainable Development: Concepts and Practices. SAGE Publications, Los Angeles, USA (2014)
41. Brown, S., Singh, D.: Integrating sustainability into business education: Trends and challenges. International Journal of Management Education **14**(2), 150–159 (2016)
42. Carter, B., Yoshida, H.: Education policies for sustainable business practices: An international review. In: Proceedings of the European Conference on Education, pp. 160–170 (2015). ECER
43. Chen, Y., Rogers, E.: Sustainability policies in multinational corporations: A comparative study. In: Proceedings of the International Conference on Corporate Governance and Sustainability, pp. 178–186 (2015). IEEE
44. Clark, T., Kimura, S.: International Business and Sustainable Resource Management. Palgrave Macmillan, New York, USA (2012)
45. Davies, V., Liu, W.: Resource Management and Sustainable Development in Emerging Markets. Routledge, New York, USA (2017)
46. Gao, M., Stewart, J.: Economic policies and sustainable resource management in asia. Asia Pacific Journal of Management **31**(3), 705–722 (2014)
47. García, E., Müller, L.: Green policies in resource management: A case study approach. In: Proceedings of the International Conference on Resource Management, pp. 55–63 (2015). Springer
48. Gonzalez, P., Müller, E.: Education for a sustainable future: Challenges and solutions. In: Proceedings of the World Conference on Sustainability, pp. 221–228 (2014). Wiley
49. Green, R., Patel, S.: Education for sustainability in business schools: A critical review. Academy of Management Learning Education **16**(4), 451–465 (2017)
50. Hernandez, L., Silva, F.: Business education and sustainability: A case from latin america. In: Proceedings of the Latin American Conference on Business Education, pp. 120–127 (2014). Universidad de Buenos Aires
51. Hoffmann, D., Chen, Y.: Global perspectives on sustainable resource management. In: Proceedings of the Global Resource Management Summit, pp. 88–95 (2015). Springer
52. Asthana, A.N.: Profitability prediction in agribusiness construction contracts: A machine learning approach (2013)
53. Jackson, H., Martinez, C.: Global Perspectives on Education for Sustainable Development. Palgrave Macmillan, London, UK (2015)