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Advancement and implementation of climate smart agriculture: A comparative analysis of India and New Zealand

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Abstract

The agricultural sector provides the essential food supply as well as sustains the human life for every nation. It acts as a solid foundation without which any country cannot achieve true economic stability or social well-being. That's why having a strong and productive agricultural sector is very important for any country. This sector ensures the food security, supports livelihoods, development, and the supply of raw materials for many industries. It becomes essential to focus on the sustainable development and growth of this sector to ensure the long-term prosperity and resilience of any country. This sector also plays a very significant role in the economies of both India and New Zealand, though the nature and scale of agricultural practices differ between the two countries. Agriculture is the major source of livelihood for a large portion of the population in India and it also contributes to the food security and rural development in India. New Zealand has a highly modernized and export-oriented agricultural sector which is known for its efficient dairy and horticultural production. Regardless of these differences, the agricultural sector remains a crucial sector supporting economic growth and environmental sustainability in both these countries. This review aims to compare the research on climate smart agriculture in India and New Zealand.

Keywords: Climate-smart agriculture (CSA), Climate change, Agricultural sector, India, New Zealand.

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Introduction

As agriculture is directly influenced by climate, climate is one of the most crucial factors influencing the production and productivity of agriculture in any country. Temperature, rainfall, humidity, and seasonal patterns directly affect crop growth, soil fertility, and overall farm productivity. Climate change significantly impacts the agriculture by changing the temperature patterns, rainfall distribution, and the frequency of extreme weather events. The rising temperatures, droughts, floods, and irregular seasons reduce crop yields and affect the health of the soil as well as impact the availability of water. Climate change poses a serious threat to the productivity of agriculture and the security of the food. This is why climate-smart agriculture has become increasingly important in the modern agricultural system. It helps farmers adapt to changing climatic conditions and it also maintains and increases the agricultural productivity. Climate-smart agriculture promotes sustainable practices to reduce greenhouse gas emissions and strengthen the resilience of farming systems. It also encourages efficient use of natural resources such as water, soil, and energy while maintaining or increasing agricultural productivity. By integrating improved crop varieties, better soil management, and efficient irrigation techniques, climate-smart agriculture helps farmers adapt to changing climatic conditions and also reduce the production risks. It also supports the long-term environmental sustainability while ensuring food security and stable livelihoods for farming communities.

MATERIALS AND METHODS

A comparative qualitative research design is used in this study to assess climate-smart agriculture (CSA) systems in New Zealand and India. Examining variations in policy frameworks, technology adoption, and impact outcomes across various agroecological and socioeconomic situations is best done using a comparative method.

The study combines thematic analysis and a systematic literature evaluation to provide a thorough synthesis of the body of knowledge regarding CSA methods and their efficacy.

RESULTS AND DISCUSSION

Climate-smart agriculture (CSA) policies in India and New Zealand reflect fundamentally different developmental priorities and institutional capacities. In India, CSA is embedded within broader rural development and food security programs such as the National Mission for Sustainable Agriculture (NMSA) and the National Innovations in Climate Resilient Agriculture (NICRA). These initiatives emphasize adaptation, risk reduction, and livelihood security, particularly for smallholder farmers [1,2&3]. The policy focus is largely reactive, addressing climate vulnerabilities such as droughts, floods, and soil degradation. In contrast, New Zealand adopts a proactive and mitigation-oriented policy framework, integrating agricultural emissions reduction targets into national climate commitments. Policies are strongly supported by scientific research and institutional coordination, enabling precise monitoring and reporting of agricultural greenhouse gas emissions [4&5]. The presence of well-developed extension systems and data-driven governance enhances the effectiveness of CSA implementation.

Comparatively, while India demonstrates strong policy intent, challenges remain in implementation due to fragmented governance and limited access to resources [6]. New Zealand's success highlights the importance of institutional coherence, policy integration, and technological infrastructure in achieving CSA objectives.

The following section presents India's progress and application of climate smart agriculture

Khatri-Chhetri *et al.,* [7] analyzed the economic benefits of climate-smart agricultural practices for smallholder farmers in the Indo-Gangetic plains of India. The study focuses that smallholder farmers adopt a variety of climate-smart agriculture practices and technologies to reduce the negative impacts of climate change and climatic variability. The adoption of such practices mostly depends on the economic benefits perceived by farmers. Research conducted among smallholder farmers in the Indo-Gangetic plains of India examined several CSA practices. This included improved crop varieties, laser land levelling, zero tillage, residue management, site-specific nutrient management, and crop diversification. From these options, the farmers showed greater preference for practices such as improved crop varieties, crop diversification, laser land levelling, and zero tillage. The results suggest that the adoption of these CSA practices will improve crop productivity and farm income while also enhancing resource-use efficiency in the rice-wheat production system. Also combining multiple CSA technologies can generate even greater benefits in terms of yield improvement and profitability. This analysis indicates that implementing CSA practices in smallholder farming systems has a significant positive influence on production efficiency and agricultural sustainability in the Indo-Gangetic Plains.

Rao [8] performed a review on big data applications in climate-smart agriculture, examining the current status and implications for agricultural research and innovation in India. It is essential for farmers and researchers to adopt climate-smart or climate-resilient approaches as climate change is increasingly threatening agricultural production systems. The integration of recent advances in big data analytics with climate and agricultural science can significantly accelerate research and innovation in climate smart agriculture. Climate smart agriculture comprises a set of technologies and practices designed to enhance farm productivity and incomes, improve adaptive capacity to climate impacts, and reduce greenhouse gas emissions. It represents a multi-objective, data-driven, and knowledge-intensive approach to agriculture, with decision-making centered at the farm level. Big data can enhance CSA in several ways. It enables the development of predictive tools that account for climate change impacts at scales relevant to decision making at the farm level. It can accelerate plant breeding programs which are aimed at improving both productivity and climate resilience. Big data also facilitates the delivery of customized, real-time information to farmers, supporting informed decisions that enhance productivity, adaptation, and mitigation outcomes. This review assesses the current state of big data applications in these areas, identifies the associated research and institutional challenges and also discusses strategies for leveraging big data to strengthen CSA research and innovation in India.

Kishore *et al.,* [9] examined the evolution of government policies aimed at promoting the development of climate-smart agriculture in India. This paper reviews the agricultural related policies and programs which are implemented by the Government of India and which also incorporate elements of climate-smart agriculture. While climate resilience is not always the explicit objective, analysis indicates that 15% of total agricultural expenditure is directed toward enhancing resilience to climate change. Major interventions include micro-irrigation, watershed development, and conservation agriculture under initiatives such as the National Food Security Mission (NFSM), National Mission for Sustainable Agriculture (NMSA), National Horticulture Mission (NHM), Rashtriya Krishi Vikas Yojana (RKVY), crop insurance, neem-coated urea, and weather advisory systems. The government has also committed investment toward CSA development, which is expected to leverage additional contributions from farmers, the private sector, and the state governments. This highlights that such large-scale resource allocation will have a great impact on the agrarian economy and the environment, given there is stronger coordination among programs and also greater participation from farmers. These findings highlight the importance of aligning policy efforts and encouraging stakeholder engagement to maximize the effectiveness of climate-smart agricultural initiatives in India.

Lopez-Ridaura *et al.* [10] conducted a study on climate-smart agriculture, farm household typologies, and food security through an ex-ante assessment in eastern India. An ex-ante assessment refers to the evaluation of a policy, project, or intervention before it is implemented. It is used to predict potential impacts, benefits as well as risks in order to support better planning and decision-making process. This research explores the challenge of ensuring social equity in agricultural development and food security interventions. It examines the food security status and livelihood activities of smallholder farm households in Bihar, India, highlighting the importance of understanding how different farming systems respond to development initiatives and environmental shocks. Using statistical analysis, the research identifies various farm household types and evaluates their potential food availability based on income from crops, livestock, and both on-farm and off-farm activities. The study further assesses the possible impacts of adopting climate-smart agriculture practices, such as conservation agriculture and improved livestock management, along with the effects of environmental shocks like drought. The findings reports that conservation agriculture can significantly improve household food availability, particularly for medium and relatively better-off cereal farmers. However, these households were also found to be more vulnerable to food insecurity during drought conditions. In contrast, households with diversified income sources, including off-farm employment, showed greater resilience to such shocks. Overall, the study emphasizes the need for careful planning and evaluation of agricultural interventions to improve smallholder food security while ensuring social equity.

Ghosh [11] examines the role of climate-smart agriculture in fostering sustainable agricultural development, ensuring food security, and reducing the adverse effects of climate change on crop productivity in India. Various technologies, practices, and services have been introduced in climate-smart villages as adaptation strategies to manage climate risks and maintain stability and sustainability in agricultural production. Farmers who adopted CSA strategies were found to achieve higher yields, productivity, and income compared to those who did not. These strategies offer significant opportunities for wider adoption, with the potential to increase crop production, enhance farm incomes, and lower greenhouse gas emissions. Strengthening agricultural extension services and linking agricultural finance with climate finance could play a crucial role in scaling up CSA technologies, making farming more sustainable, climate-resilient, and a reliable source of livelihood and food security for millions of farmers. Practices such as zero-budget natural farming provide a climate-resilient approach that can improve food and nutritional security, enhance soil fertility, and increase yields at lower cost and risk while reducing irrigation needs. Zero-budget natural farming is a farming approach that relies on natural inputs such as cow dung, cow urine, crop residues, and other locally available materials instead of chemical fertilizers and pesticides. It aims to reduce farmers' production costs to nearly zero while improving soil health, biodiversity, and sustainable crop productivity. Additionally, these practices benefit the ecosystem by improving soil organic matter, water retention, biodiversity, and by lowering air and water pollution as well as greenhouse gas emissions.

Tankha *et al.,* [12] worked on overcoming the barriers to climate smart agriculture in India. Their study examines the promotion of climate-smart agricultural practices. They focused on improved irrigation methods in India which can support both climate change mitigation and adaptation objectives by enhancing the efficient use of natural resources. Their study also offers an institutional perspective to understand the processes and mechanisms through which such agricultural transitions can be implemented. Three interconnected approaches which are institutional, sociological, and technical are applied in their study. The institutional analysis focused on understanding the stakeholders and their roles within the water-energy relationship in India, using more than 25 semi-structured interviews with key informants. The sociological aspect involved conducting surveys with over 50 farmers and equipment suppliers to explore their perspectives and factors influencing the adoption of new technologies. In addition, the technical analysis examined data on water and energy use to estimate the potential advantages of shifting toward more efficient irrigation practices. Because policymakers often favour voluntary policy measures rather than strict regulatory reforms, existing distortions within policy and market systems can create opportunities for influential actors to promote technological solutions and negotiate policy agreements that benefit multiple stakeholders. Mutually beneficial outcomes can be achieved by such arrangements and the deadlocks can be reduced in efforts to address climate change. Expanding the range of participants and interests involved in decision making can further support these agreements, as broader collaboration is often more effective than traditional two-party negotiations. The study offers valuable guidance on developing effective climate action policies, even within challenging or restrictive institutional environments. Research on climate change politics often emphasizes deadlocks and depicts the private sector as obstructive to climate action. In contrast, this paper highlights how policy reforms can be designed in mutually beneficial ways to break such stalemates, enabling technology-driven climate and environmental benefits even in contexts with limited technological capacity and economic constraints. Drip irrigation is one of the most important techniques which offers great promise but slow progress. The decision to adopt an innovation largely depends on the extent of benefits it offers. Numerous technical studies have identified the advantages of drip irrigation, which can be grouped into seven categories, as seen in table-1. Among these, the most significant benefits are reductions in water and energy use.

Table 1: Potential advantages of Drip irrigation

S.No.	Benefits	Remarks
1.	Water use	Field experiments show that sugarcane grown with drip irrigation consumes 44-55% less water compared to traditional flood irrigation.
2.	Electricity use	Improved water-use efficiency directly leads to lower electricity consumption in fields relying on groundwater pumping, with potential savings ranging from 25% to 50%.
3.	Fertilizer use	Drip irrigation reduces the need for fertilizer since, unlike flood irrigation, it minimizes the loss of nutrients that would otherwise be washed away.
4.	Crop yield	Experimental trials in Maharashtra have shown that drip irrigation can increase sugarcane productivity by approximately 23%.
5.	Drought resilience	Since drip-irrigated sugarcane uses less water, it can be more efficiently irrigated during periods of drought.
6.	Soil maintenance	Flood irrigation leads to rising soil salinity, a trend that has been observed in multiple sugarcane growing regions of Maharashtra.
7.	Labour use	Drip irrigation reduces labour requirements and allows for more flexible scheduling. For instance, during field studies, farmers reported that flood irrigation often needs to be carried out at night, increasing the risk of encounters with animals.

This study shows that climate-smart agricultural reforms can succeed even in economically constrained and technologically lagging regions when policies are designed to create mutually beneficial outcomes. Key enablers include mature technology, early state support, broad stakeholder engagement, and active private-sector participation in awareness, demonstration, and policy facilitation. Policymakers' preference for voluntary measures and the use of economic incentives often drives environmental and climate co-benefits, even when climate is not the primary agenda. Expanding the problem and solution space allows resources and interests to align, overcoming stalemates and enabling sustainable, technology-driven interventions.

Ahmad *et al.,* [13] examined the need for climate-smart agriculture in the 21st century to promote socio-economic development and climate-resilient agriculture in India from a geospatial perspective. The study reviews climate change as a major environmental challenge driven largely by the increasing concentration of greenhouse gases in the atmosphere, which threatens biodiversity and disrupts ecosystems. These changes pose serious risks to agricultural production and the livelihoods of millions of vulnerable people in India. The research analyses various datasets related to agricultural greenhouse gas emissions, poverty levels, anthropogenic biomes, crop production trends, soil moisture conditions, and projected temperature and precipitation patterns using remote sensing and GIS techniques to understand the spatial impacts of climate change. The findings indicate a rising trend in agricultural greenhouse gas emissions across several Indian states, along with noticeable regional variations in soil moisture availability across different cropping seasons. The study also highlights those arid and semi-arid regions, often associated with farmer distress, are particularly vulnerable to future climate changes. Overall, the analysis emphasizes the importance of adopting integrated strategies such as climate-smart agriculture (CSA) to address the challenges posed by climate change, enhance food production, and improve the resilience of farmers' livelihoods in India.

Aryal *et al.,*[14] examined agricultural sustainability in the context of increasing climate variability, emphasizing the role of climate-smart agriculture and related policy measures in India. The global demand for agricultural commodities is steadily increasing, while the availability of production resources continues to decline. At the same time, growing climatic variability adds further pressure on agricultural systems. To maintain long-term agricultural sustainability, production systems must be transformed to become more productive, resource-efficient, and environmentally responsible. Achieving such transformation requires coordinated actions across the entire system, including significant changes in governance structures, policies, and institutional frameworks. In this context, the study examined whether climate-smart agriculture can support climate change adaptation, mitigation, and food security in India. The findings indicate that CSA has strong potential to contribute to these goals. Integrating CSA practices into development planning through Climate-smart villages (CSVs) can generate local-level evidence and support the development of local adaptation plans of Action (LAPA), while also informing state and national climate strategies. Therefore, the study recommends incorporating CSA approaches into broader development planning processes.

Mahto *et al.,* [15] conducted a study on agrivoltaics as a climate-smart agricultural approach for farmers in India. Agrivoltaics is a climate smart agricultural approach that integrates solar energy generation with crop cultivation on the same land. Solar panels are installed above or alongside crops, allowing farmers to produce renewable energy while continuing agricultural production. This system helps improve land-use efficiency, conserve water, provide partial shade for crops, and create an additional source of income for farmers. India plays a leading role in agriculture, with a large portion of its population relying on farming for their livelihoods. However, many farmers face challenges due to outdated or unreliable agricultural practices, which in extreme cases have led to tragic outcomes such as farmer suicides. India's growing population also creates increasing demands for GDP growth and energy supply. Their study reviewed the integration of solar energy with agriculture, known as agrivoltaics, as a Climate-smart agriculture (CSA) strategy for Indian farmers. The study is further supported by a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis of agrivoltaics. This study illustrates how agrivoltaics can contribute to more sustainable and resilient agricultural practices. Key strengths identified include rural electrification, water conservation, improved crop yields, sustainable income generation, and reduced pesticide use. This study also examines the weaknesses, opportunities, and potential risks associated with agrivoltaics in the Indian context. The findings suggest that agrivoltaics can help achieve multiple objectives, including fulfilling global commitments, creating employment opportunities, providing economic stability, increasing clean energy production, conserving natural resources, and more. This study also discusses the implications, recommendations, and potential benefits of scaling up agrivoltaics adoption across India.

India's large rural population relies heavily on agriculture, which contributes about one-fifth of the GDP, yet many farmers still use traditional practices due to poverty and limited awareness. The hardships of farming, including delayed returns on investment, have contributed to alarming suicide rates. Indebtedness, poverty, and family pressures are the primary causes, and rising temperatures further increase these risks. These challenges underscore the urgent need for sustainable, high-yield, and climate-resilient agricultural practices. The following figure shows the causes of farmers' suicide identified by NCRB in the year 2014.

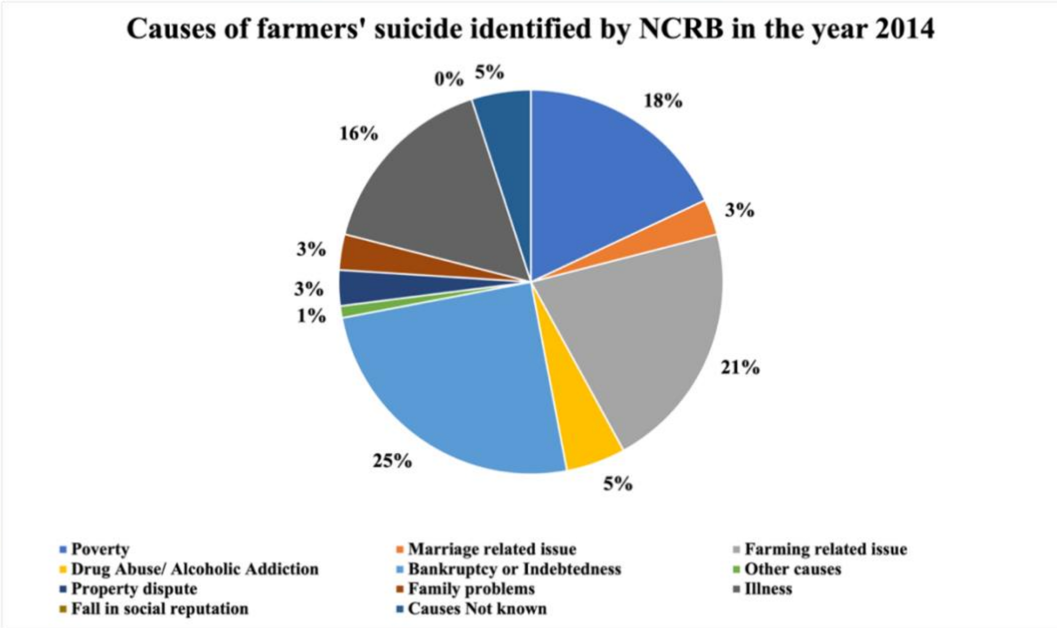

Figure 1: Causes of farmers' suicide identified by NCRB in the year 2014

Barooah *et al.*,[16] examined the intersection of gender, agricultural policies, and climate-smart agriculture in India. India's agricultural sector is facing growing challenges from the impacts of climate change. While the Government of India has implemented several programs to tackle these issues, significant gaps remain, particularly in effectively supporting women farmers. They examined the policy and implementation gaps that limit women farmers' access to climate-smart agriculture (CSA) practices and to explore how the differing roles of women and men in farming influence their needs and access to the supportive services required for adapting to climate change. This study involved a comprehensive review of India's agricultural and climate policies and programs, alongside a series of focus group discussions with farmers in Gujarat to explore challenges and identify opportunities for more effectively engaging women farmers with CSA practices. Women's heightened vulnerability to climate change and limited access to CSA practices are linked to factors such as restricted land ownership, limited credit availability, inadequate access to information and formal extension services, and multiple demands on their time. Strengthening village cooperatives and self-help groups can help improve women's access to agricultural knowledge and facilitate the adoption of CSA practices. This paper emphasizes the barriers

Indian women farmers face in accessing information and extension services, which can hinder the broader adoption of CSA practices. It addresses a critical knowledge gap by informing the development of gender-responsive policies and inclusive agricultural extension systems to support CSA adoption among smallholder farmers.

Tyagi and Haritash [17] conducted a meta-analysis examining climate-smart agriculture, improved agricultural productivity, and the carbon sequestration potential of agroecosystems in India. Carbon sequestration potential of agroecosystems refers to the ability of agricultural systems to capture and store carbon dioxide from the atmosphere in soil, plants, and biomass. This process helps reduce greenhouse gas concentrations and mitigate the impacts of climate change while improving soil health and ecosystem sustainability. Changes in climate and shifting weather patterns have had a pronounced impact on food production systems, resulting in crop losses, reduced yields, and market instability. Conventional agricultural practices that rely heavily on water and chemical inputs have also made the sector a significant contributor to carbon emissions, with implications for global climate, nutrient cycling, and food security. Climate-smart agriculture (CSA) practices offer a pathway to develop more resilient agricultural systems that balance productivity, food security, and climate change mitigation. The study synthesizes data from 116 published articles to evaluate the impact of transitioning from conventional to CSA practices on soil properties and carbon stocks in India, considering diverse soil and environmental conditions. The meta-analysis, conducted using OpenMEE and Jamovi, also reviewed the effects of CSA on crop yields. OpenMEE (Open Meta-Analysis of Ecological and Evolutionary Data) is an open-source statistical software used to conduct meta-analysis, especially in ecological and environmental studies. It helps researchers combine and analyse results from multiple studies to identify overall patterns or effects. Jamovi is a free statistical analysis software built on the R programming language that provides an easy-to-use interface for performing data analysis, statistical tests, and meta-analysis. It is commonly used for research in social, environmental, and agricultural sciences. Results indicate that practices such as conservation tillage, integrated nutrient management, and agroforestry enhance soil organic carbon accumulation compared to conventional methods, with the extent of sequestration influenced by climatic factors (temperature and precipitation), soil characteristics (pH, depth, texture), and experiment duration. Overall, CSA practices not only improve soil quality and crop yields but also sequester carbon and reduce CO_2 emissions, presenting a synergistic approach for sustainable agricultural development and supporting India's goal of net-zero emissions by 2070.

The development and application of climate smart agriculture in New Zealand are compared in the section that follows.

Negra *et al.,* [18] studied Brazil, Ethiopia, and New Zealand as leading countries in the advancement and implementation of climate-smart agriculture. The study reviews the growing importance of climate-smart agriculture (CSA) as an approach that simultaneously addresses climate-change adaptation, mitigation, and food security challenges. It highlights how different countries have incorporated CSA into their national agricultural policies through integrated and context-specific strategies. The experiences of Brazil, Ethiopia, and New Zealand demonstrate varied policy approaches to promoting sustainable and resilient agricultural systems. New Zealand has emphasized market-oriented reforms, including the removal of agricultural subsidies and strong collaboration with the private sector in research and development to enhance efficiency and resilience. The review emphasizes that developing effective CSA strategies requires coordinated national policies supported by strong institutional frameworks, stakeholder participation, and reliable information systems. Governments can adopt a mix of policy instruments such as regulations, financial incentives, public investments, and awareness programs to support CSA implementation. Many existing agricultural policies aimed at improving productivity, livelihoods, and environmental protection can serve as key components of national CSA strategies. However, stronger international cooperation and clear policy signals from global institutions are essential to encourage countries to pursue agricultural pathways that contribute to climate resilience, poverty reduction, and food security while also addressing global greenhouse gas emissions.

Hopkins *et al.,* [19] examined climate change and its implications for Aotearoa New Zealand. The study reviews the climate change context in New Zealand, noting that although the country's total contribution to global greenhouse gas emissions is relatively small due to its limited population, its emissions per capita are comparatively high. This is largely attributed to the significant role of the pastoral agricultural sector in the national economy. The literature indicates that the biophysical impacts of climate change are expected to intensify existing climatic trends, with considerable regional variations across the country. The review identifies several key risks associated with climate change in New Zealand, including economic vulnerabilities linked to global connections, potential impacts on the country's international reputation as a "clean and green" destination, and issues related to social equity. The primary mitigation strategy has been the national emissions trading scheme, although its effectiveness in encouraging behavioural change and promoting low-carbon investment has been limited. The study also highlights relatively modest engagement in global climate governance in recent years, which has raised concerns regarding the country's role in addressing global climate challenges. In addition, the research examines adaptation strategies across important sectors such as agriculture and tourism, as well as among vulnerable communities including coastal populations and Māori communities. The study also notes that while media coverage generally reflects scientific consensus on climate change, it often frames the issue within political debates. Public perceptions show ongoing uncertainty regarding the causes and impacts of climate change, sometimes viewing it as a distant risk, which may influence the level of support for climate-related policy actions.

Carroll and Daigneault [20] examined whether investing in agricultural greenhouse gas mitigation is an economically viable strategy for New Zealand to achieve its ambitious climate targets. Reducing greenhouse gas (GHG) emissions from agriculture is a critical component of meeting global climate goals, given that the sector contributes roughly 24% of total emissions. While most mitigation efforts have historically focused on industrialized farming, pastoral systems such as those in New Zealand represent a significant share of national emissions, with biogenic sources accounting for nearly half of total annual GHG output. This review synthesizes findings from studies using national level economic land use models to evaluate the costs and benefits of implementing land-based mitigation practices, both currently available and under development. The evidence suggests that the effectiveness and costs of these practices vary widely. Approaches such as methane inhibitors are highly effective but expensive, whereas targeted urine patch treatments are inexpensive but less impactful. Afforestation and emerging solutions like methane vaccines appear cost-effective and have the potential to reduce New Zealand's agricultural emissions substantially. Combining multiple mitigation strategies could achieve reduction targets ranging from 10% to 50% at costs generally lower than comparable measures in the energy and transport sectors. Sensitivity analyses indicate that widespread adoption of an affordable methane vaccine is crucial for achieving higher reduction targets, as failure to implement key practices could result in underutilized land. Importantly, the technologies and approaches examined are not unique to New Zealand and offer lessons for other countries seeking cost-effective pathways to reduce agricultural GHG emissions.

Vannier *et al.,* [21] on their New Zealand focused research developed a systems model to evaluate pathways toward resilient, sustainable, and economically viable agriculture. The study reviews the need to better understand future pathways and potential disruptions affecting the agricultural system of New Zealand, particularly in relation to environmental sustainability and agricultural productivity. Agriculture remains a central component of the country's economy, yet the sector is currently undergoing major transformations driven by climate change, shifting market conditions, stricter environmental regulations, and emerging technologies. In response to these challenges, the research highlights the importance of developing tools that can support policymakers and industry stakeholders in planning strategies that enhance agricultural profitability, resilience, and sustainability over the long term. To address this need, the study discusses the development of a systems-based decision support model that integrates multiple aspects of the agricultural sector, including production, land use, water and energy consumption, fertilizer use, emissions, and market values across key farming systems such as dairy, livestock, cropping, horticulture, and forestry. The model allows users to simulate different future scenarios to assess potential outcomes under varying technological, market, and environmental conditions. The findings suggest that while multiple development pathways can help achieve national emission reduction targets, their impacts on profitability and land-use strategies may vary. Overall, the model provides a useful framework for evaluating policy options and guiding the transition toward a more resilient, sustainable, and productive agricultural system in New Zealand, with potential applications in other countries as well.

This following section aims to compare the research on climate smart Agriculture in developed and developing countries.

Scherr *et al.,* [22] explored the transition from climate-smart agriculture to the broader concept of climate-smart landscapes. Climate-smart agriculture is increasingly recognized as requiring a landscape-level perspective to achieve multiple objectives, including food security, rural livelihoods, and climate change adaptation and mitigation. Climate-smart landscapes integrate field and farm level practices with diverse land uses and coordinated management across the landscape to generate social, economic, and ecological benefits. Effective implementation relies on institutional mechanisms such as multi-stakeholder planning, supportive governance, secure resource tenure, targeted investments, and systematic monitoring.

Chandra *et al.,* [23] researched on climate-smart agriculture, focusing on its various perspectives and conceptual frameworks. This paper presents a systematic review of the conceptualizations and contexts shaping the discourse on climate-smart agriculture (CSA) in academic and policy literature. The review highlights three main patterns: studies are heavily influenced by global policy agendas, research predominantly addresses scientific and technical issues, and there is growing emphasis on integrating the three pillars of CSA-adaptation, mitigation, and food security as a holistic solution. The analysis shows that CSA remains a relatively new concept encompassing a broad range of practices without a universally agreed set of criteria. While the three pillars are central to the CSA framework, the way these issues are framed varies across global, developing, and developed country contexts. Although there is an increasing focus on developing countries, particularly regarding smallholder agriculture, research documenting CSA experiences in developed countries is limited. The findings suggest that future CSA research should move beyond purely technical approaches and expand to diverse geographical contexts. Cross-disciplinary studies that incorporate socio-economic, political, and institutional dimensions are essential to understand how differing narratives influence the practical implementation of CSA strategies worldwide.

CONCLUSION

The comparative review of climate-smart agriculture (CSA) in India and New Zealand highlights both similarities and differences in how the two countries address climate-related challenges in agriculture. In India, most research focuses on improving the resilience of smallholder farmers through the adoption of various CSA practices such as improved crop varieties, conservation agriculture, drip irrigation, crop diversification, and climate-smart village initiatives. These studies emphasize enhancing farm productivity, strengthening food security, and improving farmers' livelihoods while reducing the vulnerability of agriculture to climate variability. Indian research also highlights the importance of supportive government policies, institutional frameworks, technological innovations, and inclusive approaches that consider gender issues and the needs of resource-poor farmers. Overall, CSA in India is largely directed toward addressing socio-economic challenges, improving adaptive capacity, and ensuring sustainable agricultural development for a large rural population dependent on farming.

In contrast, research on climate-smart agriculture in New Zealand focuses more on environmental sustainability, greenhouse gas mitigation, and the development of advanced policy and technological frameworks to manage agricultural emissions. Studies highlight the importance of integrated policy approaches, economic modelling, and systems-based decision-support tools to guide long-term agricultural planning and climate mitigation strategies. Given the country's highly commercialized and export-oriented agricultural sector, the emphasis is placed on improving efficiency, reducing agricultural greenhouse gas emissions, and achieving national climate targets while maintaining economic profitability. The comparative analysis indicates that while India prioritizes adaptation, livelihood security, and inclusive development, New Zealand concentrates more on mitigation strategies, technological innovation, and policy-driven sustainability. Together, these approaches demonstrate that climate-smart agriculture must be adapted to national contexts, balancing environmental goals with socio-economic realities to build resilient agricultural systems.

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