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The Impact of Climate-Smart Agricultural Practices on Economic Development and Sustainable Innovation in Rural China

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MODULE CODE: BGLP0014

WORD COUNT: 14576

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Abstract

This study focuses on the role of Climate-Smart Agriculture (CSA) in the development of China's rural economy and its impact on sustainable innovation. Under the dual pressures of global climate change and food security, CSA has received widespread attention as an integrated strategy to increase agricultural productivity, enhance climate resilience, and reduce greenhouse gas (GHG) emissions. As a major agricultural nation, China has widely applied CSA through policy promotion and technological innovation to promote sustainable agricultural development and rural economic diversification. However, the promotion of CSA in China still faces challenges such as regional resource disparities, high implementation costs, and difficulties in technology dissemination. This study conducts an empirical analysis to examine the implementation of CSA across different regions of China, evaluating its impact on farmers' income, environmental sustainability, and economic growth. Through quantitative analysis of multi-source data, the study verifies the effectiveness of CSA in different economic regions of China. Furthermore, the study incorporates regional entrepreneurship and education levels to provide recommendations on sustainable entrepreneurship. This research aims to fill existing gaps in the literature and provide empirical support for policymakers and practitioners, helping China achieve the goals of long-term sustainable agriculture and rural development, thereby advancing agricultural modernization and green transformation and contributing to global sustainable development goals.

Keywords: Climate-Smart Agriculture, Sustainable Entrepreneurship, Rural Economic Development in China

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List of Abbreviations

AIS - Agricultural Innovation System
CA - Conservation Agriculture
CGIAR - Consultative Group for International Agricultural Research
CSA - Climate-Smart Agriculture
CSLM - Climate-Smart Livestock Management
FAO - Food and Agriculture Organisation of the United Nations
IoT - Internet of Things
IPM - Integrated Pest Management
OECD - Organization for Economic Cooperation and Development
RBV - Resource-Based View
SDGs - Sustainable Development Goals

Acknowledgements

Firstly, I would like to extend my highest respect and sincere gratitude to all the scholars and scientists dedicated to research on agricultural and food issues. Your relentless efforts and outstanding contributions in this field have laid a solid foundation of knowledge for me and inspired me to delve deeply into the subject of Climate-Smart Agriculture. It is your unwavering pursuit of science that enables us to continuously seek innovative solutions to the challenges of global food security and environmental sustainability.

Secondly, I would like to express my special thanks to my supervisor, Professor Robert Costanza. Throughout the research process, he has provided me with selfless guidance and support. From the design of the thesis structure to the implementation of empirical analysis, his insight and expertise have been fundamental to the success of my research.

Meanwhile, I would also like to thank the Rural Industry Research Team at Zhejiang University for providing invaluable data support through the Rural Innovation and Entrepreneurship Index. This research is not only the result of my personal efforts but also embodies our shared aspirations for agricultural modernisation and green transformation. We continue to work together to contribute to the achievement of the global sustainable development goals.

Lastly, I wish to express my deepest gratitude to my family and friends. Although we are separated by great distances, your love and trust have allowed me to fully dedicate myself to my research and remain steadfast and determined in the face of challenges.

Believe in effort, and good fortune will find its way;
Believe in the land, and new growth will greet each day.

Chapter 1 - Introduction

Climate change and food security are critical issues for sustainable agricultural development. With the world population projected to reach 9.7 billion by 2050, the demand for food is expected to increase by 60%, placing immense pressure on agricultural systems(FAO, 2009). This challenge is further intensified by climate change, which disrupts weather patterns, exacerbates land degradation, and depletes water resources, threatening food production worldwide. To address these issues, the Food and Agriculture Organization (FAO) introduced the concept of Climate-Smart Agriculture (CSA), which aims to promote sustainable agricultural development by enhancing agricultural productivity, increasing resilience to climate change, and reducing greenhouse gas emissions(FAO, 2010). As a comprehensive approach, CSA has gained global attention and is seen as an important strategy for achieving sustainable agricultural goals (Thornton et al., 2018). It also aligns with several Sustainable Development Goals (SDGs), particularly Goal 2 - Zero Hunger, Goal 12 - Responsible Consumption and Production, and Goal 13 - Climate Action (Nations, 2023). By adopting sustainable agricultural practices, CSA not only helps to eliminate hunger and improve food security but also fosters more sustainable production systems and mitigates the impacts of climate change (Lipper et al., 2017).

In this global context, China, as a large agricultural country, is actively responding to these challenges(Long et al., 2016). In recent years, driven by the dual needs of economic development and achieving sustainable development goals, China's agricultural sector has experienced a significant transformation(Huang, 2022). At the core of this transformation is the widespread promotion and application of CSA(Wakweya, 2023). By integrating sustainable innovations with modern agricultural practices, CSA technologies have revolutionized traditional agricultural production methods and provided effective solutions to address food security issues and climate change challenges(Li et al., 2022). The Chinese government has introduced several policies, such as the National Agricultural Sustainable Development Plan (2015-2030) and the 14th Five-Year National Agricultural Green Development Plan (MOA, 2015; MOA, 2021), to promote the adoption and implementation of CSA technologies. These measures have not only improved agricultural productivity and resource use efficiency but also significantly enhanced the climate resilience of rural communities, reduced carbon emissions in the agricultural sector. Through the implementation of CSA, China is steadily advancing towards sustainable agriculture and rural economic development.

The relationship between Climate-Smart Agriculture and rural economic development is increasingly intertwined. By reducing resource waste, enhancing farm efficiency, and introducing innovative technologies, CSA practices not only increase farmers' incomes but also support the economic diversification of rural communities. China has made considerable progress in the application of agricultural technology and the integration of information technology, driving the development of smart agriculture(Xiong et al., 2014, Campbell et al., 2014). The application of sophisticated irrigation systems, integrated livestock utilisation technologies, modern machinery, and emerging technologies such as the Internet of Things, big data, and artificial intelligence has greatly improved agricultural productivity and resource utilisation(Subeesh and Mehta, 2021). Such innovations help farmers adapt to climate change and facilitate a new generation of agricultural entrepreneurs who build sustainable business models through technological advancements(Christian et al., 2024). This entrepreneurial ecosystem actively promotes the achievement of SDG 8 - Decent Work and Economic Growth by creating sustainable job opportunities in rural areas(Nations, 2023). Furthermore, the development of green agriculture, strengthened policy support, enhanced education and training, and the promotion of international cooperation have laid a solid foundation for the prospective growth of smart agriculture in rural China(Chen et al., 2022).

While CSA has great potential to increase agricultural resilience and productivity, its development in China faces several challenges. These challenges include regional differences in resource availability, high implementation costs, and difficulties in disseminating new technologies to farmers(Wakweya, 2023). In addition, there are limited systematic studies that specifically address the impact of CSA in different economic and environmental contexts in China(Zhao et al., 2023). Existing literature lacks research on the impacts of CSA on rural livelihoods, environmental sustainability, and economic growth in different regions of China.

Therefore, this study aims to address these gaps by investigating the impact of CSA practices on sustainable innovation and agricultural economic development in rural China. By analysing the implementation and outcomes of CSA practices in different economic regions, such as the Northeast, Eastern, Central, and Western regions(NBSC , 2011), this study will provide a comprehensive understanding of how these practices affect rural livelihoods, environmental outcomes, and economic growth.

This research focuses on the following questions:

1. How does Climate-Smart Agriculture technology impact the rural economy in China?
2. What potential opportunities for sustainable entrepreneurship and innovation

do CSA practices create?

3. How do these practices contribute to carbon reduction, environmental sustainability, and the achievement of related SDGs?

By answering these questions, this study will contribute to the literature on sustainable agriculture and rural development and provide practical insights for scaling up CSA practices to achieve China's long-term goals of sustainable agriculture and rural development.

This research is of significant academic importance. Firstly, it fills a research gap regarding the implementation and effects of CSA in China. Although there is considerable research on CSA, systematic studies focusing on China's specific context are relatively scarce. By exploring the interaction between the application of CSA technologies and rural entrepreneurship and innovation, this study provides new theoretical perspectives and empirical evidence for the fields of climate change, sustainable agricultural development, and rural economics, further deepening our understanding of the interaction between climate change and agriculture. This study is also of great social significance. By revealing the impact of CSA on rural economic development in China, it provides valuable insights for policymakers to formulate more effective agricultural and rural development policies. Importantly, the widespread adoption of CSA contributes to global efforts to combat climate change and ensure global well-being(Sang et al., 2024).

The structure of this dissertation is as follows: Chapter 1 introduces the background, research questions, research objectives, and significance of this study and outlines the organization of the entire dissertation. Chapter 2 systematically reviews the relevant literature on CSA, sustainable entrepreneurship, and their intersecting fields, focusing on theoretical and empirical gaps in existing research and highlighting the unique contributions and significance of this study. Chapter 3 details the research methodology, including the specific processes of data collection, sample selection criteria, and variable explanations, ensuring the reliability and validity of the research findings. Chapter 4 presents the core findings of the study, explaining the impact of CSA practices on China's agricultural economic development through empirical analysis and further examining regional differences. Chapter 5 provides an in-depth discussion of the research results, analysing how local policy frameworks drive innovation and entrepreneurship in the agricultural sector. Finally, Chapter 6 summarises the main findings, discusses the theoretical and practical implications of this study, and offers suggestions and directions for future research, aiming to guide further research and application of CSA.

Chapter 2 - Literature Review

2.1 Introduction to CSA

2.1.1 Definition and Concept of Climate-Smart Agriculture

Climate-Smart Agriculture is a comprehensive approach designed to transform agricultural systems to be more resilient, sustainable, and adaptive to the challenges posed by climate change(Taylor, 2018). Various leading institutions have contributed to the definition and conceptualization of CSA, highlighting its role in addressing global climate and food security challenges.

In October 2010, FAO launched a paper entitled Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation as a background document for the conference in The Hague. The concept of CSA was formally defined as an approach that guides actions to transform agri-food systems into greener and more climate-resilient practices. CSA focuses on three core objectives: sustainably increasing agricultural productivity and incomes, adapting to and enhancing resilience against climate change, and minimising and/or eliminating greenhouse gas emissions as much as possible (FAO, 2010; FAO, 2024). Since then, with the evolution of global climate change policies and the participation of multiple stakeholders, the concept of CSA has been developed and reshaped.

Based on this, the World Bank and the Organization for Economic Cooperation and Development (OECD) have expanded on the integrated nature of CSA, stressing that it goes beyond technological innovation. CSA involves a combination of policy measures, financial tools, and capacity-building initiatives to address the interconnected challenges of food security and climate change. The World Bank defines CSA as an approach to managing landscapes (cropland, livestock, forests, and fisheries) that enhances productivity, boosts resilience, and reduces emissions simultaneously(World Bank, 2024). Similarly, the OECD stresses the importance of cross-sectoral collaboration and supportive policies for the effective implementation of CSA and the achievement of global food security and climate goals(OECD, 2021).

The FAO's 2022-2031 Strategic Framework underlines CSA's alignment with the Four Betters Principles: better production, better nutrition, better environment, and better lives, ensuring an inclusive agricultural transformation(FAO, 2021). CSA aligns with international goals, including the SDGs and the Paris Agreement(FAO, 2024). The United Nations Framework Convention on Climate Change (UNFCCC) views CSA as key to achieving these goals and encourages its integration into Nationally Determined Contributions (NDCs), emphasising its role in reducing greenhouse gas emissions and enhancing farmers' climate resilience(UNFCCC, 2019).

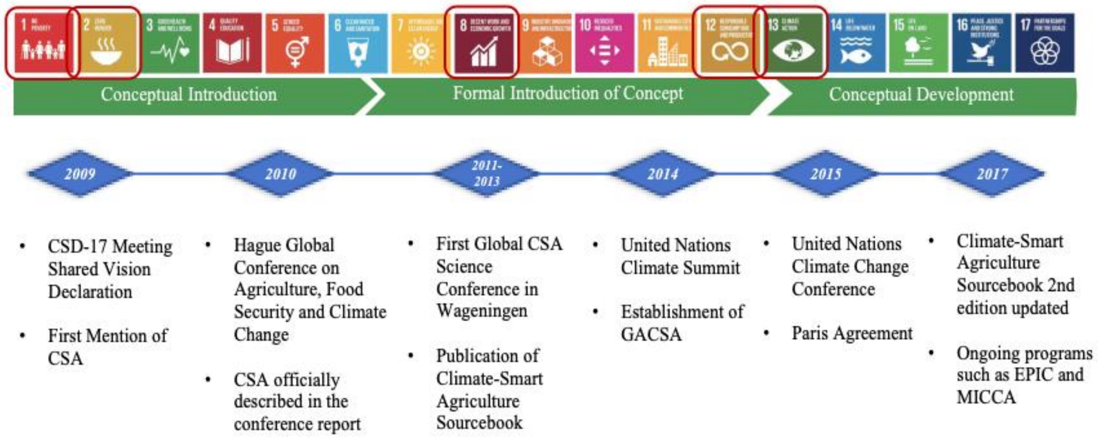


Figure 1- Selected Milestones of Climate-Smart Agriculture (CSA) Research

Source：(Xu et al., 2023)

Beyond institutional frameworks, research shows that the practical implementation of CSA requires adaptation to specific regional and climatic conditions. Studies from the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS) emphasise CSA’s adaptability to different climatic and socio-economic contexts. These studies indicate that the effective implementation of CSA relies on tailoring agricultural practices to local environmental and resource conditions(CCAFS, n.d.). For instance, they highlight the importance of drought-resistant crops and optimised irrigation technologies in arid regions, while recommending soil and water conservation measures in humid areas to mitigate flood risks(CCAFS, 2021).

Overall, CSA represents a transformative approach that integrates the environmental, economic, and social dimensions of sustainable development. As the global community continues to face the challenges posed by climate change, CSA offers a comprehensive solution that balances the need for increased food production with the imperatives of environmental stewardship and resilience building.

2.1.2 CSA Practices and Technologies Worldwide

Climate-Smart Agriculture comprises a wide range of practices and technologies that are collectively designed to enhance agricultural resilience, boost productivity, and mitigate the impacts of climate change(Taylor, 2018). These practices are diverse and tailored to specific agricultural environments, involving techniques such as crop rotation, inter-cropping, no-till or reduced tillage, and conservation agriculture(Al-Shammary et al., 2024). The management strategies extend to risk management, irrigation optimization, land management, and market structure adjustments(Partey et al., 2018). Scholars further categorise CSA measures into various approaches, including water-smart, soil-smart, climate-smart, carbon-smart, varietal-smart, nutrition-smart, and market-smart methods(Khatri-Chhetri et al., 2017).

Category	Practice Measures
Soil-Smart	Conservation agriculture: no-till, reduced tillage, crop rotation, fallowing, intercropping, cover cropping; planting methods: strip planting, ridge/furrow; mulching; organic farming; increasing soil biodiversity; low disturbance planting.
Water-Smart	Irrigation: drip, sprinkling, subsurface drip, solar-powered drip; distributed irrigation; regulated deficit irrigation; physical infrastructure: planting pit technology, laser leveling, terracing, trenching, bund planting, riverbank stabilization.
Climate-Smart	Crop insurance; climate information services (e.g., weather-based agricultural consultation), improving weather forecasting, developing climate forecasting systems; adjusting crop growth periods; optimal planting windows; adjusting planting or harvest times.
Carbon-Smart	Agroforestry systems, feed management, selecting efficient livestock feed, integrated pest management; chemical input management: reducing chemical use and using biological control; improved manure management; reducing open burning.
Variety-Smart	Spatial crop diversity; improved crop varieties (e.g., mixed cropping, drought-resistant crops); high-yield crop selection; high carbon-sequestering varieties; optimal crop management.
Nutrient-Smart	Organic fertilizers (e.g., green manure, compost, animal manure); crop-livestock integration; in-situ composting; organic amendments; retaining agricultural biomass as a natural soil amendment; promoting the use of organic fertilizers.
Market/Institution-Smart	Strengthening inter-sectoral and local connections; enhancing farmers' learning abilities; developing emergency preparedness, financial services, market information, and risk management strategies.

Table 1 - Type of Climate-Smart Agriculture(CSA) Practice Options

Source:(Aggarwal et al., 2018)

Successful implementation of CSA often requires the integration of multiple measures, prioritising actions based on local conditions, and ensuring strong institutional support through coherent policies and financial investments(Chen et al., 2022). Research indicates that CSA practices not only promote the sustainable transformation of agricultural systems but also increase crop yields and incomes(Campbell et al., 2014).

For example, CSA practitioners typically achieve higher incomes compared to traditional farmers, primarily because CSA practices help maintain yields under climate stress(Hellin et al., 2023). Global pilot projects and case studies provide valuable insights that demonstrate the potential for wider adoption of these practices(Mwangi et al., 2021).

Building on this understanding, the following section takes an in-depth review in key CSA practices, including conservation agriculture, water management, and climate-smart livestock management. The implementation of these practices across different regions will be explored, with an assessment of their effectiveness in achieving CSA objectives and a discussion of the challenges involved in scaling them up.

2.1.2.1 Conservation Agriculture

Conservation Agriculture (CA) is a fundamental practice within CSA. It focuses on minimising soil disturbance, maintaining permanent soil cover, and promoting plant diversity through crop rotation and cover cropping (FAO, 2023). These techniques significantly contribute to the resilience of agricultural systems under changing climatic conditions. In Moldova, CA practices such as no-till and strip-till farming have been widely adopted as key strategies, which shows their importance in maintaining soil health and agricultural productivity in temperate climates(Boincean and Lal, 2014). In contrast, Bangladesh faces a distinct set of climatic and environmental challenges due to its tropical monsoon climate, such as flooding, soil salinisation, and water scarcity(Dhar et al., 2018). Here, CA practices, including reduced tillage, crop residue management, and alternate wetting and drying (AWD) in rice cultivation, are integrated into the broader CSA framework to address these issues(Labios et al., 2021).

The differences between Moldova and Bangladesh highlight the adaptability of CA to varying environmental conditions, emphasising the need for tailored approaches in implementing CA across diverse climates(Giller et al., 2015). Despite regional differences, both countries face similar obstacles, particularly for smallholder farmers. The high initial costs of CA machinery and the required expertise pose significant barriers(Jayne et al., 2010). Additionally, financial constraints, limited access to credit, and inadequate extension services hinder the widespread adoption of CA in Bangladesh(Dhar et al., 2018). Despite these challenges, both countries are committed to adapting CA to their specific regional needs, demonstrating the scalability and flexibility of these practices globally.

2.1.2.2 Efficient Water Resource Management

Water resource management practices include drip irrigation, sprinkler systems, and remote sensing technologies that optimise water use and enhance agricultural resilience and productivity in the face of climate change(Pachiappan et al., 2024, Sarfraz et al., 2023). For instance, in severely water-scarce areas, drip irrigation is prioritised. This technology delivers water directly and precisely to the plant roots, minimising evaporation and runoff, thus improving water use efficiency(Van der Kooij et al., 2013). In Egypt, the Sustainable Agriculture Investments and Livelihoods (SAIL) project promotes drip irrigation to address water scarcity in newly reclaimed lands(El-Ramady et al., 2013). Similarly, in Saint Lucia, drip irrigation has stabilised vegetable production during the dry season, ensuring a steady crop supply even under water-scarce conditions (FAO, 2021) .

More developed regions like Italy, have adopted advanced irrigation systems and are supported by strong institutional frameworks and robust agricultural infrastructure. Pressurised systems, including drip and sprinkler technologies, are integral to Italy's CSA strategy. These systems contribute to soil and water conservation(Pino et al., 2017). In addition, Georgia offers a holistic approach to CSA, with the project synergistically combining pressurized irrigation with conservation agriculture practices. Reduced tillage and soil mulching,for example, improve both water efficiency and soil health(FAO, 2021).

In addition to drip irrigation, some regions in Africa and the Near East have adopted cutting-edge technologies like remote sensing to enhance water resource management. Tools like the Water Productivity Open-access Portal (WaPOR) facilitate real-time monitoring of water productivity, enabling data-driven decisions to address gaps in water management(Blatchford et al., 2020). This approach is particularly valuable in areas where traditional methods cannot manage the widespread impacts of climate change.

Efficient water resource management technologies not only improve water use efficiency but also strengthen climate resilience across regions(Gupta et al., 2020).

2.1.2.3 Climate-Smart Livestock Management

Climate-Smart Livestock Management (CSLM) is a vital component of CSA, focusing on enhancing the resilience of livestock systems while reducing greenhouse gas emissions and ensuring sustainable productivity(FAO, 2017). CSLM includes a range of practices, such as improved grazing management, integrating livestock with crop systems, efficient use of water and resources, and adopting technologies that mitigate the environmental impacts of livestock farming(Amole and Ayantunde, 2016).

In Ecuador, CSLM is closely integrated with sustainable crop production, particularly within cocoa farming systems. Silvopastoral systems, which incorporate trees into pastures, enhance biodiversity, provide shade, and improve carbon sequestration. These systems contribute to ecological sustainability while significantly reducing the carbon footprint of livestock farming(FAO, 2021). Ecuador also emphasises efficient grazing management and biogas systems, which convert livestock manure into renewable energy, demonstrating a commitment to reducing methane emissions and promoting sustainable livestock practices(Gaitán et al., 2016).

In Botswana, traditional practices such as rotational grazing and the use of drought-resistant livestock breeds are emphasised. These practices are well-suited to the country's semi-arid environment, ensuring that livestock systems remain resilient to climate change while supporting the long-term sustainability of livestock production(Batisani et al., 2020). By integrating biodiversity, renewable energy, and climate adaptability, CSLM contributes to the broader goals of CSA across diverse contexts.

The effective implementation of CSA practices represents the need for innovative solutions to build resilient agricultural systems capable of withstanding climate change. However, understanding the theoretical frameworks behind these practices is equally vital. The next part explores the intersection of sustainable entrepreneurship and CSA, examining how innovative business models can enhance the scalability and sustainability of climate-smart agriculture.

2.2 Theoretical Framework: Sustainable Entrepreneurship and CSA

2.2.1 Concept of Sustainable Entrepreneurship

Sustainable entrepreneurship is increasingly recognised as a transformative approach that combines economic value creation with the pursuit of social and environmental goals(Thompson et al., 2011). Unlike traditional entrepreneurship, which primarily focuses on financial profit, sustainable entrepreneurship emphasises the triple bottom line—balancing profit, people, and the planet(Rosário et al., 2022). Some scholars define sustainable entrepreneurship as the process of "discovering, creating, and utilising opportunities to create future goods and services that sustain the natural and/or communal environment and provide development gains for others" (Shepherd and Patzelt, 2011).

Schaper(2016) points out the role of entrepreneurs in directly addressing environmental challenges through their enterprises, promoting environmental innovation and green business practices. These entrepreneurs go beyond merely creating new ventures; they are fundamentally focused on embedding sustainability at the core of their business operations. Similarly, Schaltegger and Wagner (2011) argue that sustainable entrepreneurs are distinguished by their creativity and adaptability, innovating by developing business models that are intrinsically linked to ecological and social values, thereby driving sustainability-oriented innovation. Tobias et al.(2013) expand on this concept by introducing the idea of transformative entrepreneurship, which goes beyond profit-making to address deep-rooted social issues such as poverty and conflict resolution. This perspective emphasises the creation of systemic change through rethinking business operations and social contributions, which is essential for advancing broader sustainable development goals.

Sustainable entrepreneurship demonstrates its unique impact in addressing complex global challenges by integrating social, environmental, and economic goals to drive systemic change. Thompson et al. (2011) argue that sustainable entrepreneurship collectively addresses social and environmental problems as a cross-cutting strategy for correcting market failures and contributing to societal well-being. This integrated perspective reveals how sustainable entrepreneurship can drive cross-sectoral systemic change, utilising overlapping goals to achieve wider social and environmental impacts. Lüdeke-Freund (2020) highlights this by directly linking sustainable entrepreneurship with innovative business models, emphasising that the value created, delivered, and captured by companies can simultaneously benefit society and the environment.

This multifaceted approach highlights the dynamic and evolving nature of sustainable entrepreneurship, which requires diverse strategies combining business innovation, social inclusion and environmental stewardship.

2.2.2 Sustainable Entrepreneurship in Agriculture

In the context of agriculture, sustainable entrepreneurship is not only important in transforming agricultural practices and promoting eco-friendly farming methods but also in fostering rural economic development, and innovative environmental management solutions(Sargani et al., 2020).

Existing research indicates that sustainable entrepreneurship in agriculture is influenced by a combination of factors, including entrepreneurial skills, knowledge levels, and the external environment. McElwee (2006) emphasises that farmers need to develop entrepreneurial skills such as opportunity recognition and strategic resource management to remain competitive in a rapidly changing agricultural environment. Mupfasoni et al.(2018) add that knowledge levels, particularly in environmental sustainability, significantly influence farmers' ability to recognise opportunities. Groups with higher knowledge levels can identify and exploit entrepreneurial opportunities based on their knowledge, while those with lower knowledge levels tend to rely more on existing opportunities within the environment. This knowledge gap reveals areas for improvement in education and policy support. To achieve sustainable entrepreneurship in agriculture, Sargani et al. (2020) stress the importance of integrating the triple bottom line into agricultural entrepreneurship education. And they recommend that policymakers focus on the diverse backgrounds of farmers, enhancing education levels and providing targeted support to increase the sustainability and overall success of agricultural entrepreneurship.

Some scholars argue that entrepreneurial success relies not only on the development of individual skills but also on the collaborative influence of multiple external stakeholders, such as researchers and policymakers(Pindado and Sánchez, 2017). This perspective suggests the importance of synergistic support from the entire agricultural ecosystem to achieve innovation success. Building on this, the concept of the Agricultural Innovation System (AIS) has been proposed, emphasising the need for multi-party collaboration and supportive policies to bridge gaps in the innovation process(Grovermann et al., 2019). In line with this focus on collaboration, Dias et al.(2019) suggest that sustainable technological innovation, which balances economic viability with environmental responsibility, has become a central trend in agricultural entrepreneurship. However, Gadanakis et al. (2024) argue that technological innovation alone isn't enough for agricultural transformation. They think innovations in management and human capital are also necessary. Thus, they advocate for a holistic approach that integrates these elements to achieve sustainable agricultural development.

These studies show that sustainable agriculture entrepreneurship requires both entrepreneurial skills and collaborative efforts from stakeholders, supported by policies. The AIS framework helps to bridge innovation gaps and enhance collaboration, and is centered on the integration of sustainability and technology.(Hall and Clark, 2010). Future success will depend on effectively combining technology, management, and human capital to create a resilient agricultural ecosystem, driving transformation and balancing economic, social, and environmental goals.

2.2.3 Integration of Sustainable Entrepreneurship and CSA

Recent research states the interrelationship between sustainable innovation and the effective adoption and scaling of CSA practices. It is instrumental in addressing the challenges posed by climate change and ensuring agricultural productivity and sustainability. Bryan et al.(2013) emphasise the significance of entrepreneurship in integrating CSA practices into local agricultural systems. Especially in communities with limited resources, entrepreneurial activities are relevant to the widespread adoption of innovative agricultural practices. Based on this, Lipper et al. (2014) argue that innovative CSA technologies are a key component in achieving sustainable success in agriculture. And agricultural entrepreneurs are often at the forefront of developing and applying these technologies. Aggarwal et al.(2018) extends this view by proposing the climate-smart village approach. This combines technological innovation with community-driven entrepreneurial efforts, providing a model for effectively scaling CSA across different regions.

To better understand the intersection of sustainable entrepreneurship and CSA, theoretical frameworks such as the Resource-Based View (RBV) and Diffusion of Innovations theory can be utilised(Dearing and Cox, 2018, Madhani, 2010). These theories explain how CSA drives sustainable entrepreneurship by transforming agricultural resources into strategic assets. From the RBV perspective, the success of entrepreneurial ventures depends on the ability to acquire and utilise valuable, rare, inimitable, and non-substitutable resources (Madhani, 2010). CSA technologies, as valuable resources, offer farmers and entrepreneurs a competitive advantage by optimising the use of land, water, and energy, thereby enhancing the profitability and sustainability of agricultural enterprises while also creating new business model opportunities based on sustainable agriculture(Tang et al., 2019).

Additionally, Diffusion of Innovations theory explains how CSA technologies spread within agricultural communities(Wejnert, 2002). The successful diffusion of CSA practices is influenced by factors such as perceived benefits, technological complexity, and the cultural and social dynamics of the target groups(Dearing and Cox, 2018). Economic incentives like subsidies or market access can accelerate the adoption of CSA technologies, while high initial costs and technical knowledge barriers may hinder their spread(Partey et al., 2018). Understanding these dynamics is crucial for designing effective policies and programmes that support the scaling of CSA-driven entrepreneurial ventures.

In summary, the integration of sustainable entrepreneurship and CSA not only drives agricultural innovation and development but also offers a practical pathway to addressing climate change. This integration requires the synergistic interaction of technological innovation, entrepreneurial skills, and strategic scaling methods, supported by theoretical frameworks that guide practice and policy development.

2.3 Rural Entrepreneurship and CSA in China

Having explored the relationship between sustainable entrepreneurship and the advancement of rural CSA practices, it is clear that these concepts are critical to addressing the climate challenge and promoting sustainable agricultural development. China, one of the world's largest agricultural economies and a country experiencing rapid rural transformation, offers a unique case for examining the intersection of CSA and rural entrepreneurship(Chen et al., 2022, Huang, 2022). The combination of government policies, digital advancements, and evolving socio-economic conditions has profoundly shaped rural entrepreneurship in China and provides valuable insights into the potential for expanding CSA in similar contexts(Chen et al., 2022).

2.3.1 Background of Rural Entrepreneurship in China

The Chinese government has systematically developed a series of policies to promote rural entrepreneurship, starting with the Targeted Poverty Alleviation initiative in 2015. This policy laid the foundation by providing financial resources, training, and market access to help rural residents start businesses as a means to lift themselves out of poverty(The State Council, 2015a). Meanwhile, the Mass Entrepreneurship and Innovation initiative, launched in 2015, expanded these efforts nationwide, creating a supportive environment for startups across the country, including in rural areas, by improving access to finance and reducing bureaucratic barriers(The State Council, 2015b). While Targeted Poverty Alleviation focused on helping individuals escape poverty, the Mass Entrepreneurship and Innovation initiative aimed to cultivate a broader entrepreneurial ecosystem, encouraging innovation as a driver of economic growth in rural areas.

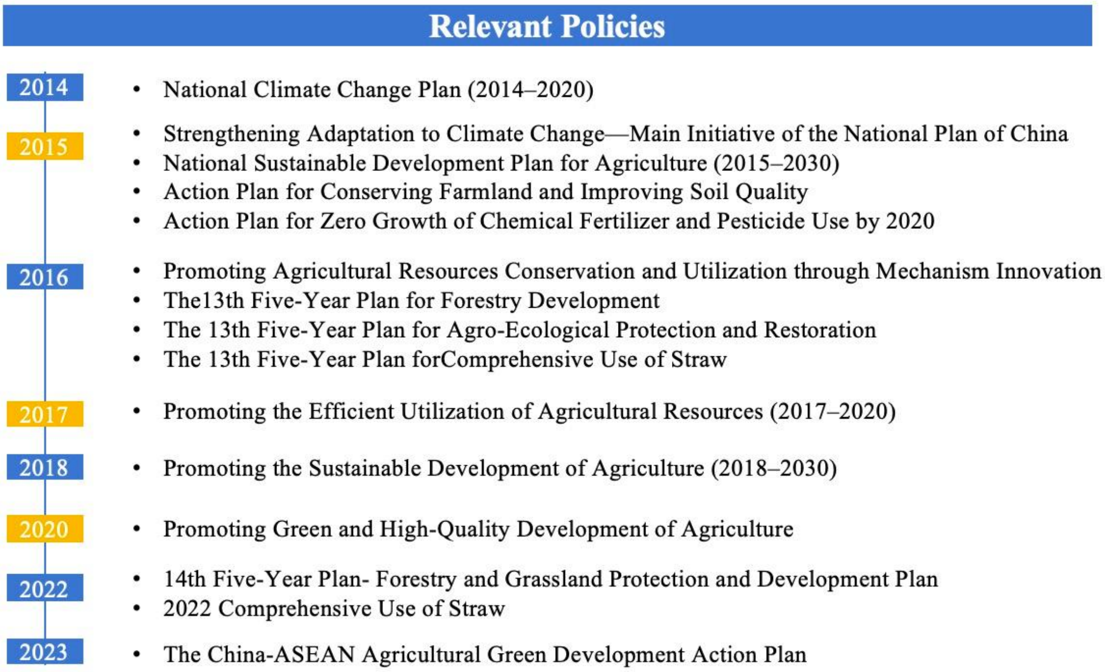
The Rural Revitalisation Strategy of 2017 further integrated entrepreneurship into wider rural development goals, emphasising innovation in agriculture, tourism, and e-commerce as tools for economic and social revitalisation(The State Council, 2017). The Digital Village Construction strategy, introduced in 2019, advanced these efforts by focusing on bridging the urban-rural digital divide. By equipping rural entrepreneurs with digital tools and platforms, the policy facilitated the scaling of rural businesses and supported the integration of modern technology into traditional industries(The State Council, 2019). These successive policies demonstrate a clear progression from poverty alleviation to sustained, innovation-driven rural revitalisation. Throughout this period, the annual No. 1 Central Document has consistently prioritised rural entrepreneurship, providing continuous policy support tailored to the evolving needs of rural communities(MOA, 2024).

Research has shown the impact of these policies on rural China. Naminse, Zhang, and Zhu (Naminse et al., 2019) focus on how targeted poverty alleviation has facilitated rural entrepreneurship by providing essential resources, training, and market access. They emphasise that these tailored strategies have not only lifted individuals out of poverty but have also fostered sustainable economic growth by embedding entrepreneurship within rural communities. Mei et al. (Mei et al., 2022) further highlight the role of digital infrastructure in advancing rural economies by narrowing the urban-rural divide and fostering innovation. These strategies have promoted sustainable development by enhancing information access, improving infrastructure, and supporting entrepreneurship, particularly in the digital sector. Moreover, recent studies further explore the broader implications of these policies on sustainable livelihoods, arguing that these policies have encouraged environmentally sustainable practices, such as eco-tourism and organic farming, which enhance the resilience of rural communities(Liu et al., 2023, Pan et al., 2024). These findings represent the importance of a multifaceted approach that integrates both traditional and digital strategies in driving long-term sustainable development and poverty reduction across rural China(Yu et al., 2022).

As the Chinese government's policies to promote rural entrepreneurship continue to evolve, the combination of these policies and smart agriculture is providing new opportunities for rural economic development. Next, I will explore China’s specific achievements in promoting smart agriculture practices.

2.3.2 Policies and Innovative Practices of CSA in China

Since the FAO introduced the CSA framework, China has progressively integrated CSA into its agricultural strategies. In 2014, China’s government formally included CSA in the National Climate Change Plan, which represented the gradual integration of CSA into China's policy agenda (NDRC,2014). By 2015, China will focus on technologies that increase agricultural resilience and reduce greenhouse gas emissions. The government released the National Sustainable Development Plan for Agriculture(MOA, 2015). Since then, the Chinese Academy of Agricultural Sciences and several universities initiated a series of pilot projects on water conservation, energy efficiency, emissions reduction, and sustainable soil management.



Relevant Policies

2014
- National Climate Change Plan (2014–2020)

2015
- Strengthening Adaptation to Climate Change—Main Initiative of the National Plan of China
- National Sustainable Development Plan for Agriculture (2015–2030)
- Action Plan for Conserving Farmland and Improving Soil Quality
- Action Plan for Zero Growth of Chemical Fertilizer and Pesticide Use by 2020

2016
- Promoting Agricultural Resources Conservation and Utilization through Mechanism Innovation
- The13th Five-Year Plan for Forestry Development
- The 13th Five-Year Plan for Agro-Ecological Protection and Restoration
- The 13th Five-Year Plan forComprehensive Use of Straw

2017
- Promoting the Efficient Utilization of Agricultural Resources (2017–2020)

2018
- Promoting the Sustainable Development of Agriculture (2018–2030)

2020
- Promoting Green and High-Quality Development of Agriculture

2022
- 14th Five-Year Plan- Forestry and Grassland Protection and Development Plan
- 2022 Comprehensive Use of Straw

2023
- The China-ASEAN Agricultural Green Development Action Plan

Figure 2 - Policies Related to CSA in China

Source: (Xu et al., 2023)

From 2016, there has been a notable expansion in the adoption of CSA practices, particularly in impoverished and ecologically vulnerable regions. The Chinese government increased investments in research and development, introducing innovative models such as smart farms and digital agriculture(Mei et al., 2022). These initiatives were carefully designed for the specific ecological and resource conditions of various regions, and the unique characteristics of China’s traditional smallholder farming(Xie et al., 2021). For example, in the black soil region of Northeast China, conservation tillage techniques like straw mulching and no-till planting were encouraged, leading to improved soil health and substantial increases in crop yields and ecological benefits(Chen et al., 2011). In the North China Plain, encompassing Hebei and Anhui provinces, water-saving irrigation and crop rotation practices were introduced to combat water scarcity, optimise soil fertility, and enhance pest control, thereby boosting agricultural sustainability(Chen et al., 2022). In Jiangsu province, an integrated rice-crayfish farming system was implemented, which saw the natural synergy between rice and crayfish used to reduce chemical inputs. This approach improves water use efficiency, and generates additional income for farmers(Jiang and Cao, 2021). These region-specific practices reflect China’s strategic approach to addressing local agricultural challenges. They combine modern technologies with traditional farming methods to strengthen agricultural resilience and address the environmental impacts of climate change.

Year	Province	Pilot Projects
2014	Henan and Anhui	Climate-Smart Major Grain Crops Production Project
2016	Yunnan	Yunnan Early-Season Rice Climate-Smart Agriculture Pilot Project
2016	Gansu	Hexi Corridor Climate-Smart Agriculture and Ecological Cultivation Demonstration
2017	Qinghai	Climate-Smart Grassland Ecological System Management Project
2017	Inner Mongolia	Bashang Area Climate-Smart Agriculture Demonstration Project for Semi-Arid Regions
2018	Hubei	Safe, Sustainable, and Smart Agriculture Demonstration Project
2021	Liaoning,Heilongjiang, Shandong, and Hebei	Northeast Black Soil Conservation and Health Promotion Project
2023	Hubei and Hunan	Green Agricultural and Rural Revitalization Program

Table 2- China's Climate-Smart Agriculture Pilot Projects

Source:(Xu et al., 2023)

China has also actively engaged in international collaborations to support CSA implementation. For instance, in 2014, the World Bank's China Integrated Modern Agriculture Development Project introduced efficient irrigation systems, climate-resilient crops, and micro weather stations in six provinces. These techniques benefited around 380,000 farmers with weather updates and agricultural guidance. This project showed the value of data-driven agricultural methods and supported the formation of farmer cooperatives and water user associations(World Bank, 2022). It also made CSA more widely adopted. Additionally, FAO has published studies on China's CSA policies and investments, providing case studies and policy recommendations to further develop CSA(World Bank, 2016).

These joint efforts have created synergies and demonstrated how adaptive policies and technological innovations can effectively balance food security and climate objectives. It illustrates China's constructive engagement in addressing the challenges of climate change.

2.3.3 Challenges and Opportunities in CSA Entrepreneurship in China

There is no doubt that CSA offers significant opportunities for the sustainable development of China’s agricultural sector. The advancement of CSA in China is aligned with the national goals of carbon peaking and carbon neutrality. This creates avenues for innovation in low-carbon agricultural technologies, resource efficiency, and sustainable farming practices(Raihan et al., 2023). Several scholars have examined the benefits and wider impacts of CSA practices on sustainable livelihoods. For example, Zhao et al. (2023) emphasise the advantages of using biochar, noting its capacity to improve soil fertility, sequester carbon, and increase crop yields. Sardar et al.(2021) further highlight the potential of CSA practices to contribute significantly to poverty alleviation.

However, the widespread application of these technologies faces several major challenges. A key issue is the difficulty of aligning agricultural subsidies and market-driven mechanisms with CSA objectives. Achieving this alignment will require stronger policy and institutional support to integrate modern technologies with traditional farming practices (Westermann et al., 2018). Additionally, significant barriers such as high production costs, inconsistent results across different environments, and a lack of awareness and technical knowledge among farmers further limit the scalability of CSA practices(Wakweya, 2023). These challenges suggest that, while CSA holds considerable promise, its broad adoption will necessitate overcoming these economic and technical hurdles.

In summary, the current state of CSA in China reflects both the potential and the challenges of this approach. Although the benefits of CSA are evident, its successful implementation and scalability will require focused efforts in policy reform, education, and technological innovation. By addressing these challenges, CSA could become a powerful driver of sustainable development and entrepreneurship in rural China.

2.4 Research Gaps and Future Directions

Despite the progress made in advancing Climate-Smart Agriculture in China, several critical research gaps must be addressed to fully unlock its potential in fostering innovation and rural entrepreneurship.

Firstly, there is a significant lack of comprehensive quantitative studies evaluating the impact of CSA adoption across different regions of China, particularly regarding its economic viability. Although existing research points out the benefits of CSA, systematic comparisons across varying climatic and socio-economic contexts are limited(Zhao et al., 2023). Furthermore, the economic feasibility of CSA practices remains underexplored. More detailed studies are needed to assess the return on investment for rural entrepreneurs, considering both short-term and long-term costs and benefits. Such analysis could inform policy decisions and encourage broader adoption by demonstrating the economic potential of CSA practices (Kangogo et al., 2021).

Another critical area of concern is the integration of advanced technologies in CSA, such as precision farming, has yet to be fully examined. Although pilot projects have shown promise, further research is required to evaluate whether these technological advancements can be effectively scaled across larger populations in China (FAO, 2023). Investigating these aspects will be essential for optimising CSA practices and ensuring their scalability and effectiveness in supporting sustainable agricultural development (Zhao et al., 2023).

Addressing these research gaps through targeted research can optimise CSA practice in China. By providing sufficient evidence on the long-term impacts, economic viability, and scalability of CSA, future research can guide policy decisions and investments. CSA can not only contributes to sustainable agricultural development, but also supports rural entrepreneurship and poverty reduction(FAO, 2024). To this end, this study will explore the economic viability, regional adaptability, and integration of advanced technologies of CSA practices to optimise their impact on sustainable development and rural entrepreneurship in China.

Chapter 3 - Methodology

3.1Research Design

This study adopts a quantitative research approach with a focus on empirical analysis. Specifically, a multivariate regression model is used to investigate the impact of Climate-Smart Agriculture (CSA) practices on rural economic performance and sustainable innovation in China. The analysis is based on secondary data(Chamberlain, 1982), primarily drawn from the National Bureau of Statistics of China, the China Rural Statistical Yearbook, and the China Agricultural Machinery Industry Yearbook. These data sources provide detailed information on CSA practices, agricultural production, and relevant economic indicators. A comprehensive set of independent, dependent, and control variables are used to rigorously assess the effectiveness of CSA interventions under varying conditions(Chamberlain, 1982).

This study provides an overview and analysis of China's agricultural economy, based on statistical data at both the national and regional levels. By analysing data from 2015 to 2022, the research examines the evolving trends in rural residents' income and its composition across different economic regions. To present these changes and trends more intuitively, a variety of visual charts will be employed to show the income levels of rural residents(Midway, 2020), the proportions of various income components, and the changes across different regions over time. This establishes a solid foundation for the subsequent empirical analysis.

Subsequently, statistical analysis is conducted using Stata software. This includes testing correlations between variables, checking for multicollinearity, and performing multivariate regression analysis(Kohler and Kreuter, 2005). The aim is to determine whether CSA adoption has a positive effect on agricultural economic performance and the environment. To be specific, the study examines the relationship between CSA practice - such as conservation tillage area, water-saving irrigation, and livestock manure utilization rates - and variables such as rural per capita disposable income.Control variables, including total power of agricultural machinery, grain crop output, and disaster-affected crop areas, are incorporated to account for potential confounding factors that could obscure the true effects of CSA adoption. The regression models are designed to quantify these relationships and provide reliable insights into the effectiveness of CSA practices(Chamberlain, 1982).

The use of secondary data allows for large-scale analysis across the country, assessing the impact of CSA techniques on rural economic development and innovative activities(Johnston, 2014). This approach is both cost-effective and time-efficient while providing a sufficient sample size to ensure the reliability and significance of the findings. Besides, secondary data also enables the observation of long-term trends in CSA adoption and its impact on agricultural productivity and entrepreneurship. This approach ensures data reliability while enhancing the external validity of the research, making the findings applicable to a broader context(Vartanian, 2010).

3.2 Sample Selection and Data Collection

The sample for this study comprises data from 34 provincial-level administrative regions in China. However, Hong Kong, Macau, and Taiwan were excluded due to a lack of available data. Then, the four municipalities of Beijing, Shanghai, Tianjin, and Chongqing were excluded because of their relatively small areas of cultivated land compared to major agricultural provinces. Especially, like Beijing and Shanghai have economies primarily centered on the service and high-tech sectors, with agriculture representing only a minor portion(Kroeber, 2020, Wang and Leng, 2012). Including such regions could introduce significant data variability and distort the overall data structure.

Figure 3 - China's 34 Provincial Administrative Regions and Economic Zones
Source:Self-made

After these exclusions, the sample retained 27 provinces. These were then further screened and stratified according to China's economic regions (NBSC, 2011), focusing on areas with active CSA adoption and entrepreneurial activities. The final selected provinces include 3 in the Northeast (Liaoning, Jilin, Heilongjiang); 5 in the East (Hebei, Jiangsu, Fujian, Shandong, Guangdong); 6 in the Central region (Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan); and 6 in the West (Inner Mongolia, Sichuan, Yunnan, Shaanxi, Gansu, Xinjiang), totaling 20 provinces. This regional stratification ensures balanced representation across different economic zones, providing more targeted insights into the relationship between CSA practices and rural innovation(Creswell, 2014).

As previously mentioned, data collection for this study relies on secondary sources. The original plan was to analyse data from 2015 to 2023, corresponding with the period of China's targeted poverty alleviation initiative. However, as data is only available up to 2022, the study focuses on the years 2015 to 2022, covering 8 years. This timeframe ensures the analysis includes the most recent trends and developments in CSA practices. And these datasets include a wide range of comprehensive indicators, including agricultural production statistics, information related to CSA technology adoption, and government policies and economic development statistics relevant to rural areas in China. Utilising these secondary data sources allows for extensive nationwide analysis while ensuring consistency and accuracy throughout the study (Johnston, 2014).

3.3 Variables Explanation and Hypotheses

The variables selected for this study cover a range of factors related to rural economic development and sustainability and the impact of CSA practices. These variables allow for an in-depth examination of how CSA adoption affects economic and environmental outcomes in rural China. By integrating dependent, independent, and control variables, this study is to build a framework to understand the multifaceted effects of CSA practices on rural livelihoods.

According to the key economic indicators for rural areas as outlined in the China Rural Statistical Yearbook, rural per capita disposable income was selected as the dependent variable representing rural economic development among seven indicators. Per capita disposable income measures the average income retained by rural households after taxes and deductions, serving as a core indicator of rural economic well-being(de Castro, 2006). It can directly reflect the actual earnings of farmers from economic activities. Similarly, per capita consumption expenditure, as part of a robustness analysis, which reflects rural household consumption patterns, is used to indicate improvements in living standards and economic vitality(de Castro, 2006). The two variables both provide important insights into the financial health of rural areas, reflecting the success of agricultural activities. And they will help evaluate whether CSA practices have contributed to income growth and increased consumption in rural communities.

Variables	**Source**	**Code**
Dependent Variables		
Per Capita Disposable Income of rural household(yuan)	National Bureau of Statistics of China	DI
Per Capita Consumption Expenditure of Rural Households(yuan)	National Bureau of Statistics of China	CERH (Used by Stable Analysis)
Independent Variables		
Area of conservation tillage(khm^2)	China Agricultural Machinery Yearbook	AOCT
Water saving irrigated area （khm^2)	China Agricultural Machinery Yearbook	WSIA
Comprehensive utilization rate of livestock and poultry manure(%)	China Rural Statistical Yearbook	COUL
Agricultural carbon emissions(1000ton)	Calculated by the Author(explained later)	ACE
Control Variables		
Output of Grain Corps(1000tons)	China Rural Statistical Yearbook	OOGC
Total Power of Agricultural Machinery(10000 kw)	China Rural Statistical Yearbook	PM
Areas Affected by Natural Disaster(1000 hectares)	China Rural Statistical Yearbook	ND

Table 3- Variables Selection and Sources

Key independent variables include the Area of conservation tillage and the Water-saving irrigated area, which are crucial indicators of land and water resource management. Conservation tillage contributes to preserving soil fertility, reducing erosion, and decreasing reliance on chemical inputs(Busari et al., 2015). Meanwhile, Water-saving irrigated area measures the implementation of efficient irrigation practices, crucial in regions where water scarcity is a growing concern(Kulkarni, 2011). Another key independent variable is the Comprehensive utilization rate of livestock and poultry manure, representing the adoption of circular economy principles in agriculture. This practice reduces waste, enhances efficiency, and generates environmental benefits by repurposing manure as organic fertilizer or bioenergy(Dhanya et al., 2020). These variables are fundamental to understanding how CSA practices improve resource management and contribute to enhanced agricultural output and rural economic gains.

In addition, agricultural carbon emissions are important for assessing the impact of agricultural practices on the environment. It is calculated using established methods that take into account the various factors that contribute to emissions and examine whether CSA practices can reduce emissions without sacrificing economic growth(Wang, Liao and Jiang, 2020). The formula for calculating these emissions follows the approach outlined by Ding et al.(2022).

Variables	**Source**	**Carbon emission factor**
Agricultural carbon emissions(1000ton)		
Volume of Effective Component of Chemical Fertilizer(10000 tons)	National Bureau of Statistics of China	0.89kg/kg
Use of Agricultural Plastic Film	National Bureau of Statistics of China	5.18kg/kg
Use of Agricultural Diesel Oil(10000 tons)	National Bureau of Statistics of China	0.59kg/kg
Use of Agricultural Pesticide(10000 tons)	National Bureau of Statistics of China	4.93kg/kg
Total Sown Areas of Farm Crops(1000 hectares)	National Bureau of Statistics of China	312.6kg//hm^2
Irrigated Area（khm^2)	National Bureau of Statistics of China	266.48kg/hm^2

Table 4 - Variables, Factors and Sources for Agricultural Carbon Emission Measurements
（Detailed calculation process can be found in Appendix 5）

In addition, this study incorporates several control variables to ensure that the effects of CSA practices are accurately measured. The output of Grain Corps is a baseline indicator of agricultural productivity, allowing the analysis to account for income and expenditure fluctuations driven by overall production levels (Jin et al., 2010). Similarly, the Total Power of Agricultural Machinery is included to reflect the degree of mechanization in rural agriculture. Given that mechanization levels can vary significantly across provinces, this variable helps to ensure that any observed effects of CSA practices on income and sustainability are not merely due to differing levels of mechanization(Verma, 2006). Additionally, Areas Affected by Natural Disasters are considered as control variables to account for external shocks, such as floods, droughts, or other natural events, which can severely disrupt agricultural productivity(Xiao, 2011). By controlling for these factors, the study reduces the risk of bias from extreme environmental events that vary regionally.

Given the variables selected for this study, the following hypotheses will be tested:

H1: CSA adoption is positively associated with rural per capita disposable income.

H2: The impact of CSA practices varies across different economic regions.

H3: Reducing carbon emissions through CSA practice will positively influence the economic performance of rural areas.

To test the hypotheses and quantitatively assess the impact of these variables on rural disposable income per capita, the following regression model was used:

$$di=\alpha+\beta_1 \cdot aoct+\beta_2 \cdot wsia+\beta_3 \cdot cuol+\beta_4 \cdot ace+\beta_5 \cdot oogc+\beta_6 \cdot pm+\beta_7 \cdot nd+\epsilon$$

In this model, di represents the dependent variable—rural per capita disposable income—while the independent variables include factors such as CSA adoption metrics and control variables. The coefficients from β_1 to β_7 reflect the influence of each independent variable on the dependent variable.And α represent the constant term, and ϵ is the error term (Kohler and Kreuter, 2005).

The analysis of these variables allows for a comprehensive examination of how CSA practices influence rural income, consumption, and sustainability. By adjusting for external factors and focusing on key indicators of agricultural and environmental performance, the study seeks to generate valuable insights into the role of sustainable agricultural practices in advancing rural development in China.

3.4 Data Cleaning and Preparation

After data collection, a data preparation process will be undertaken to ensure the quality and completeness of the data set. This process includes addressing missing values and identifying and treating outliers to refine the data for analysis. For example, the China Agricultural Machinery Yearbook contains some missing values that require careful handling. And in order to address it, linear regression imputation was applied to fill in the missing data for conservation tillage in 2022 and water-saving irrigated areas from 2021 to 2022. These imputation techniques are crucial for maintaining the integrity of the dataset, preventing incomplete data from distorting the analysis, and ensuring a more accurate reflection of trends without introducing inconsistencies (Tamraparni Dasu and Johnson, 2003).

Regarding agricultural carbon emissions data, there is a lack of certain key variables for 2022. However, the complexity of the calculation process made it inappropriate to impute the missing data. To preserve the accuracy and reliability of the carbon emissions data, it was decided to retain only the available data up to 2021. Although this decision excludes the final year of emissions data, slightly reducing the sample size for the regression analysis, the impact on the statistical power of the model is expected to be minimal. The missing data represents only a small fraction of the overall dataset, so the effect on the regression results is likely negligible(Tamraparni Dasu and Johnson, 2003). By maintaining the precision of the carbon emissions data, the analysis avoids potential biases that could arise from estimated values, ultimately leading to more reliable findings.

3.5 Ethical Considerations

Since this study relies entirely on publicly available secondary data, there are no ethical concerns related to privacy or the handling of personal information. However, the research will adhere strictly to academic integrity and data usage protocols. This includes ensuring that all data sources are legally and appropriately obtained, with clear attribution given to the sources (Johnston, 2014). Ensuring transparency in the data analysis process is also a priority, with every effort made to document methods and data sources to maintain the reliability and credibility of the research findings.

Data integrity is a key concern, and every effort will be made to ensure the accuracy and reliability of the datasets used in this research. Rigorous data cleaning and preparation processes will help mitigate risks of misinterpretation or bias that could arise from outliers or missing data. These steps are essential for upholding the validity and impartiality of the results. Special attention will be given to resolving any data inconsistencies to ensure that conclusions are based on solid, trustworthy data (Panter and Sterba, 2011).

3.6 Limitations of the Study

This study has several inherent limitations due to its reliance on secondary data. First, certain years or regions may lack complete data, which could limit the comprehensiveness and accuracy of the analysis. Besides, while secondary data offers a wide scope, it may not always capture the finer details required for a more nuanced understanding of CSA adoption and its impacts on environment(Vartanian, 2010).

Another limitation relates to causal inference. Because the study primarily utilizes cross-sectional data, it may not definitively establish cause-and-effect relationships between CSA practices and the development of the agricultural economy. The analysis will identify correlations and associations. Future research could enhance this study by using longitudinal data or incorporating fieldwork to explore these relationships in greater depth and to validate the conclusions drawn here.

Chapter 4 - Findings

4.1 Overview of China's Agricultural Economy

From 2015 to 2022, the per capita disposable income of rural residents in China showed steady upward trend. The eastern region consistently recorded the highest income levels with steady growth, reflecting its advanced economic development. Although the western region started from a lower base, it experienced the fastest growth, indicating rapid economic progress in that area. The central and northeastern regions saw relatively stable income growth, though the northeastern region's growth rate was slightly lower. Overall, while the living standards of rural residents across China have improved, large income disparities between regions remain, representing the uneven development of regional economies.

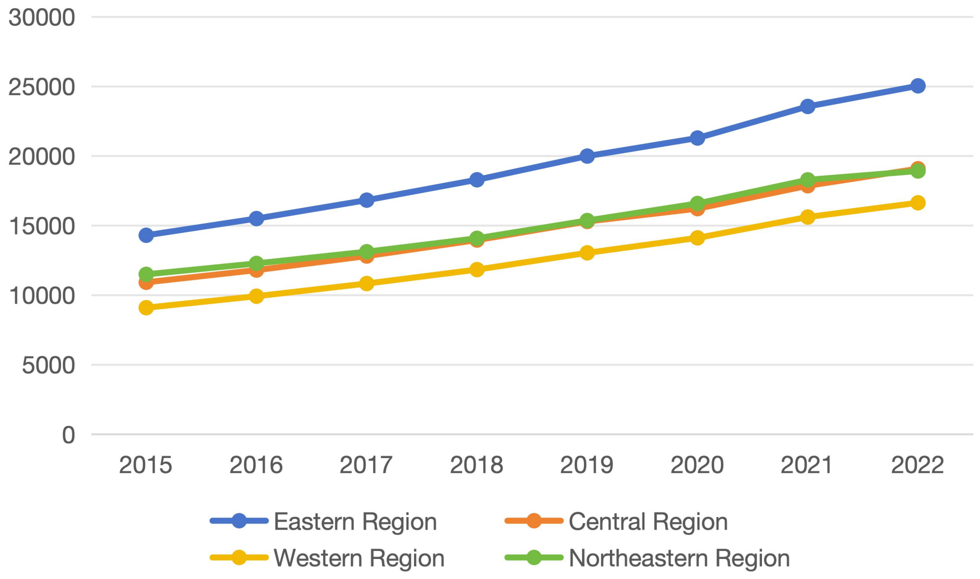


Figure 4 - Per Capita Disposable Income of Rural Residents in China's Different Regions(unit:¥)

Source: China Rural Statistical Yearbook

In terms of income composition for rural residents, from 2015 to 2022, operating income from the primary sector, particularly agricultural income, steadily increased and became the main source of income. Although operating expenses, especially agricultural expenditures, also rose during this period, the growth rate of income outpaced that of expenses, indicating an improvement in the economic efficiency of the primary sector in rural areas. However, post-2020, income and expenditures in the livestock industry declined, likely due to shifts in market demand, the impact of the pandemic, and environmental policies(Phillipson et al., 2020).

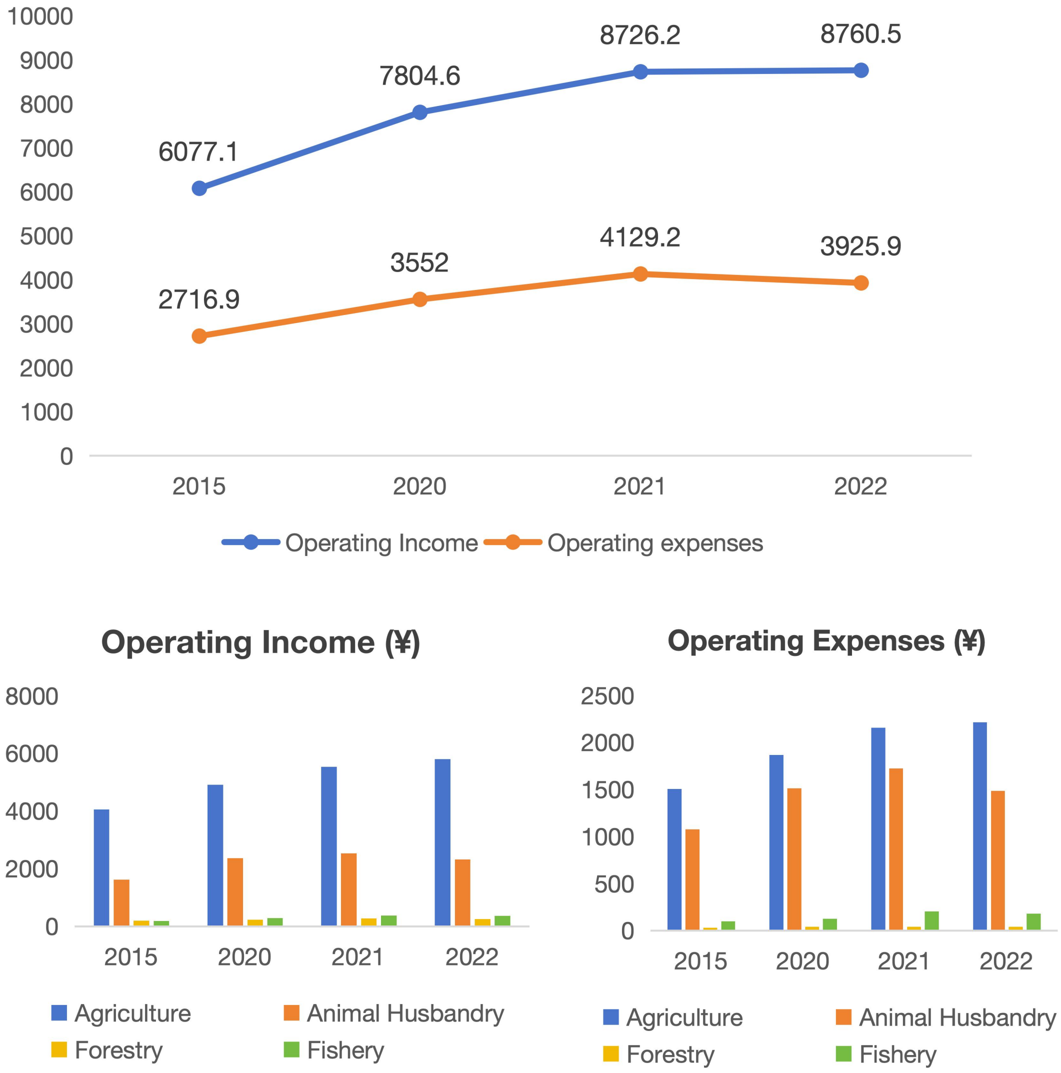


Figure 5 - Operating Income and Expenses of the Primary Sector(unit:¥)

Source:China Rural Statistical Yearbook

As rural per capita disposable income continues to rise across China, an empirical analysis will be conducted to examine the impact of CSA on this income growth. The analysis aims to assess the effectiveness of promoting CSA in various regions and its tangible contribution to rural economic development.

4.2 Empirical Analysis

4.2.1 Descriptive Statistical Analysis

Using a sample that includes 20 provinces from different economic regions of China, the descriptive statistical analysis of the variables shows significant regional differences in the four independent variables: area of conservation tillage(AOCT), area of water-saving irrigation(WSIA), comprehensive utilization rate of livestock(CUOL), and agricultural carbon emissions(ACE). The standard deviations for AOCT and WSIA are relatively large, indicating that conservation tillage has been widely adopted in some regions while not yet implemented in others, and that water-saving irrigation techniques are also unevenly promoted across different areas. The mean value of CUOL is 18.49 with a small standard deviation, suggesting that the promotion of livestock and poultry waste utilization is relatively consistent across regions. In addition, the large standard deviation of ACE reflects significant differences in agricultural carbon emissions between regions, which may be related to variations in the scale of agricultural production and the application of environmental technologies.

Variable	Obs	Mean	Std. Dev.	Min	Max
aoct	160	435.749	548.186	0	2990
wsia	160	1590.42	1139.687	295.86	4504.27
cuol	160	18.49	6.661	5.92	27.61
oogc	160	3075.041	1823.441	477.28	7867.72
di	160	14935.45	3918.572	6936	28486
nd	160	413.163	428.832	13.3	2663.7
pm	160	4587.731	2787.482	1228.27	13353.02
ace	140	443.252	190.185	186.69	995.75

Table 5 - Result of Descriptive Statistical Analysis

Regarding the control variables, grain output (OOGC) reveals substantial differences in agricultural productivity across provinces, likely influenced by factors such as climate, geographical conditions, and agricultural technology. The mean value of total power of agricultural machinery (PM) is 4,587.731 with a standard deviation of 2,787.482, indicating that some regions have a higher level of agricultural mechanization, leading to improved production efficiency. The variable for crop area affected by natural disasters (ND) highlights the significant impact of natural disasters on agricultural production, with some provinces experiencing frequent natural disasters that severely affect local farmers' income.

These significant differences among the variables reflect the uneven levels of agricultural development, the promotion of environmentally friendly technologies, and disaster management capabilities within different economic regions. To enhance rural disposable income, the application of conservation tillage, water-saving irrigation, and comprehensive utilization of livestock and poultry waste, combined with improvements in grain output, agricultural mechanization, and disaster resilience, could serve as important drivers of economic development in various regions.

4.2.2 Correlation Analysis

The correlation analysis reveals a significant positive relationship between the comprehensive utilization rate of livestock and poultry waste (CUOL) and rural per capita disposable income (DI), with a correlation coefficient of 0.371 (p = 0.000). This indicates that the application of this environmental technology can directly increase farmers' income, for instance, through the production of organic fertilizers or biogas. Additionally, the correlation coefficient between the area under water-saving irrigation (WSIA) and income is 0.139, which is close to the threshold for significance (p = 0.079) but remains relatively limited. This suggests that while water-saving irrigation technology may have a positive impact on farmers' income, the effect is not particularly strong.

Variables	(1)	(2)	(3)	(4)	(5)
(1) di	1.000				
(2) aoct	0.045	1.000			
	(0.573)				
(3) wsia	0.139	0.240*	1.000		
	(0.079)	(0.002)			
(4) cuol	0.371*	-0.029	-0.199*	1.000	
	(0.000)	(0.715)	(0.012)		
(5) ace	0.082	0.248*	0.586*	-0.027	1.000
	(0.335)	(0.003)	(0.000)	(0.754)	

*** *p<0.01,* ** *p<0.05,* * *p<0.1*

Table 6 - Result of Correlation Analysis

The lack of significant correlation between the area under conservation tillage (AOCT) and agricultural carbon emissions (ACE) with rural disposable income(DI) may be due to the fact that the impact of these variables on residents' income is not immediately apparent in the short term. This necessitates longer periods of practice and evaluation. Conservation tillage primarily improves soil quality and long-term productivity, while agricultural carbon emissions reflect the intensity of production activities, which have a smaller direct effect on farmers' short-term income(Aziz, Mahmood and Islam, 2013). Moreover, differences in policies, resource allocation, and technological application across various economic regions may further diminish the statistical significance of these variables concerning income. This will be explored in more detail in the subsequent heterogeneity analysis.

4.2.3 Multicollinearity

To detect potential multicollinearity issues among the independent variables in the model, this study employs the Variance Inflation Factor (VIF) for analysis. VIF is a key indicator used to assess the degree of multicollinearity. Typically, a VIF value exceeding 10 suggests a significant multicollinearity problem(O’ brien, 2007).

Variables	VIF	1/VIF
pm	6.94	0.144098
ace	6.68	0.149590
oogc	4.59	0.218019
aoct	2.14	0.467659
wsia	1.73	0.576977
nd	1.43	0.699482
cuol	1.28	0.783998
Mean VIF	3.54	

Table 7 - Result of Multicollinearity

As shown in the table, the average VIF value for the independent variables in this study is 3.54, indicating that the model does not suffer from severe multicollinearity issues. Therefore, the subsequent regression analysis can proceed without the need for extensive adjustments to address multicollinearity concerns.

4.2.4 Model Selection

Before conducting the empirical analysis, the F-test and Hausman test were performed to validate the appropriateness of the chosen regression methods(Chmelarova, 2007). Initially, the choice between the mixed effect regression model and the fixed effects model was assessed. The F-test yielded a p-value of 0, leading to the rejection of the mixed effect model hypothesis and the selection of the fixed effects model.

	F -test	**P-value**
Value	58.49	0.0000

Table 8 - Result of F-test

Additionally, the Hausman test was used to decide between the random effects model and the fixed effects model(Chmelarova, 2007). The test results indicated that the random effects model should be rejected in favor of the fixed effects model.

Hausman	
Prob > chi2	0.0000

Table 9- Result of Hausman test

4.2.5 Linear Regression Analysis

The regression model in this study aims to identify which agricultural production and environmental factors significantly impact rural per capita disposable income (DI). The dependent variable is DI, while the independent variables include the AOCT, WSIA, CUOL and ACE. The control variables are OOGC,PM,ND. Model (1) presents the regression results for the independent variables alone, while Model (2) includes the control variables. The results from these models offer important insights.

	(1)	(2)
	di	di
aoct	1.850***	1.748***
	(4.123)	(4.091)
wsia	6.765***	6.302***
	(6.701)	(6.477)
cuol	1291.098***	1152.892***
	(9.290)	(8.409)
ace	-1.742	-6.024
	(-0.310)	(-1.105)
oogc		2.225**
		(2.123)
pm		0.599***
		(3.118)
nd		-0.268
		(-0.787)
_cons	-1.98e+04***	-2.41e+04***
	(-4.185)	(-4.489)
N	140	140
R^2	0.836	0.856
F	147.361	95.945

***p<0.01, **p<0.05, *p<0.10

Table 10 - Result of Linear Regression Analysis

Model (1) indicates that the area under conservation tillage, water-saving irrigation, and the comprehensive utilization rate of livestock and poultry waste have a positive impact on rural per capita disposable income. The regression coefficients for these variables are significantly positive at the 1% confidence level(Kohler and Kreuter, 2005). This suggests that using climate-smart agricultural technologies can notably enhance farmers' income. The promotion of conservation tillage and water-saving irrigation on income is highly significant, suggesting that this practice effectively increases crop yields and brings direct economic benefits to farmers. In this case, the coefficient of the comprehensive utilisation rate of livestock and poultry waste is much larger than the other variables because its unit is a percentage while the others are area.

Agricultural carbon emissions do not show a significant impact on farmers' income. While carbon emissions reflect the intensity and scale of agricultural activities, their direct effect on income is minimal. However, the negative correlation indicates that farmers adopting climate-smart agricultural technologies have successfully reduced carbon emissions without sacrificing productivity, thereby enhancing income. This reflects a shift toward efficient and sustainable agricultural production, where improved resource use efficiency and lower production costs lead to better economic returns for farmers. This phenomenon demonstrates that sustainable agriculture and economic benefits can go hand in hand, with environmental practices not only protecting the environment but also increasing farmers' incomes.

In Model (2), after incorporating control variables, both natural disasters and the level of mechanisation show significant effects on the dependent variable. The promotion of agricultural mechanisation significantly increases production efficiency and reduces labour costs, thereby enhancing farmers' incomes. The development of mechanisation has led to larger production scales and greater efficiency, creating more economic benefits for farmers. Grain output also has a positive effect on income, aligning with the common understanding that increasing grain production directly increases farmers' incomes, given that grain is a core agricultural product.

The relationship between the area of crops affected by natural disasters and per capita disposable income is not significant. This suggest that, within the current sample, natural disasters have not significantly reduced farmers' incomes, possibly due to effective mitigation measures or strong disaster resilience in the sampled regions.

4.2.6 Robustness Test

In this robustness test, rural per capita consumption expenditure (REPC) is used as the dependent variable, which similarly reflects the economic status and quality of life of rural residents. Other independent variables and control variables are unchanged. It can be seen that the regression coefficients of the main independent variables are still significantly positive at the 1% confidence level. The overall impact of the independent variables on REPC is significant, confirming the robustness of the results.

	(1) repc	(2) repc
aoct	1.416***	1.366***
	(3.200)	(3.163)
wsia	4.664***	4.451***
	(4.686)	(4.526)
cuol	1052.665***	940.172***
	(7.683)	(6.785)
ace	-7.864	-11.352**
	(-1.421)	(-2.060)
oogc		0.691
		(0.652)
pm		0.525***
		(2.700)
nd		-0.381
		(-1.106)
_cons	-1.17e+04**	-1.21e+04**
	(-2.512)	(-2.237)
N	140	140
R^2	0.784	0.802
F	105.504	65.202

***p<0.01，**p<0.05，*p<0.10

Table 11- Result of Robustness Test

The robustness test results show that the positive effects of CSA practice on rural per capita consumption expenditure remain consistent across different models. Although some control variables, such as grain output and the area of crops affected by natural disasters, did not show significance, the effects of the primary independent variables were robustly validated. Therefore, these findings remains highly effective and reliable under various conditions.

4.2.7 Heterogeneity Analysis

Through the heterogeneity analysis, in different economic regions, there are significant differences in how the independent variables affect DI. For instance, in the northeastern region, conservation tillage has a notably positive effect on farmers' income, which is closely related to the national policy emphasis on protecting the black soil in this area(Wang et al., 2007). Besides, the effective use of water-saving irrigation has achieved significant results in both the northeastern and western regions of China, with particularly outstanding effects in the arid western areas. Furthermore, the comprehensive utilisation rate of livestock and poultry waste is the most consistent and significant positive factor across all four economic regions. In every region, the promotion of this environmentally friendly technology has significantly increased farmers' income. This indicates that whether in developed or underdeveloped areas, the CUOL contributes to enhancing agricultural efficiency and environmental quality.

	(1) di	(2) di	(3) di	(4) di
aofp	1.829***	2.488	-8.436***	2.711
	(5.628)	(0.953)	(-4.242)	(1.072)
wsia	7.125**	0.073	-1.477	7.968***
	(2.513)	(0.022)	(-0.392)	(7.987)
cuol	844.035***	1746.833***	1019.714***	952.183***
	(3.269)	(4.137)	(4.556)	(4.894)
ace	-29.107*	-9.877	-71.600***	-10.588
	(-1.801)	(-0.768)	(-3.463)	(-1.386)
oogc	0.928	2.563	-1.151	5.087***
	(0.967)	(0.386)	(-0.409)	(3.857)
pm	0.686	0.400	-0.146	0.795
	(1.465)	(0.948)	(-0.397)	(1.407)
nd	-0.064	0.509	-0.865	-0.016
	(-0.238)	(0.250)	(-1.361)	(-0.025)
_cons	-9556.709	-2.94e+04	38590.501**	-2.63e+04***
	(-0.904)	(-1.468)	(2.477)	(-4.858)
N	21	35	42	42
R^2	0.971	0.859	0.912	0.924
F	52.601	20.035	43.116	50.601

***p<0.01, **p<0.05, *p<0.10

Table 12 - Result of Heterogeneity Analysis

In contrast, farmers' income is inversely related to agricultural carbon emissions, especially in the central region, where the reduction in carbon emissions has markedly improved farmers' income. This reflects that as farmers in the central region gradually adopt low-carbon farming practices, such as precision fertilisation and ecological planting, energy consumption and carbon emissions in agricultural production have significantly decreased. These green technologies not only reduce environmental pollution but also lower production costs and increase land productivity.

These results reveal the trends and influencing factors of rural residents' income growth across different regions of China, particularly highlighting the significant positive impact of environmentally friendly agricultural technologies on farmers' income. The next chapter will discuss the policy implications of these findings and explore how to further promote CSA to achieve more balanced rural economic development and environmental sustainability.

Chapter 5 - Discussion

Through in-depth analyses of national and regional statistics, It has been found that the promotion and application of Climate-Smart Agriculture has significantly increased the disposable income of rural residents. By integrating technological innovation with ecological conservation, CSA has helped farmers enhance productivity while mitigating environmental damage in the face of climate variability. Ultimately it achieves a win-win outcome of economic and environmental benefits.

Nationally, practices such as conservation tillage, water-saving irrigation, and integrated utilisation of livestock waste have shown a significant positive impact on rural per capita disposable income in our empirical analysis. However, the effects vary across different regions, particularly in the Northeast and Western regions, which have distinct natural conditions and agricultural economic foundations. In the Northeast, conservation tillage has effectively improved soil quality and agricultural productivity, leading to a steady increase in farmers' incomes. And in the arid Western regions, water-saving irrigation techniques have enhanced water resource efficiency, alleviating the challenges of water scarcity in agricultural production. These regional differences highlight the importance of locally adapted agricultural practices in promoting sustainable rural economic and agricultural development.

To better illustrate these regional differences, the discussion will be structured by economic regions, with an analysis of specific CSA practices in each area. Also, the impact of these agricultural technologies on carbon emissions will be examined, along with how technological innovation and entrepreneurial opportunities can further promote sustainable agricultural development. Through detailed analyses by subregion, this study will reveal the effectiveness of climate-smart agricultural practices and their innovation potential in different economic regions, providing empirical support and policy recommendations for the sustainable transformation of Chinese agriculture.

5.1 Discussion on the Use and Impacts of CSA Practice in Various Regions

5.1.1 Conservation tillage in the Northeast

The promotion of conservation tillage has been effective in increasing agricultural productivity and farmers' incomes. Improved soil quality has led to stable crop yields and reduced the fluctuations caused by soil degradation. In addition, no-tillage technology reduces the frequency of farm machinery operations and fuel consumption, significantly lowering production costs(Wang et al., 2007). The combination of these technologies allowed farmers to maintain or even increase yields while reducing expenses, thereby increasing disposable income. The results of the heterogeneity analysis show that this income growth is particularly significant in the Northeast. Behind this positive effect, the national and local governments have attached great importance to the protection of black land in Northeast China in recent years. Through a series of policy support and scientific and technological innovations, conservation tillage has been gradually promoted and applied.

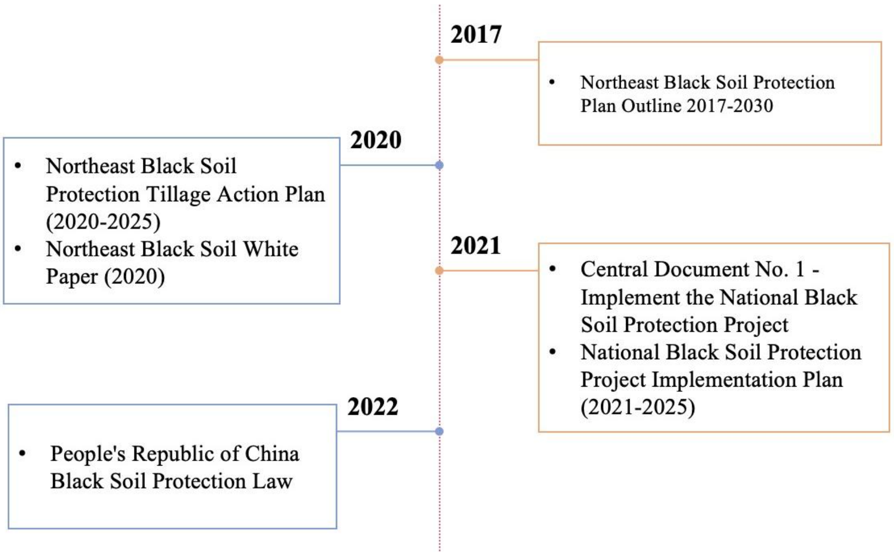


Figure 6 - Policies and Documents for Conservation Tillage in the Northeast

Source:Self-Made

The following figure shows the area of Northeast black soil conservation tillage in different provinces in recent years. In addition to Heilongjiang, Jilin, and Liaoning, it includes the four eastern leagues of Inner Mongolia (namely Hulunbuir City, Hinggan City, Tongliao City, and Chifeng City). The figure clearly shows that a significant expansion of the area of conservation tillage on black soils in the Northeast, indicating China's continued efforts and investment in black soil conservation.

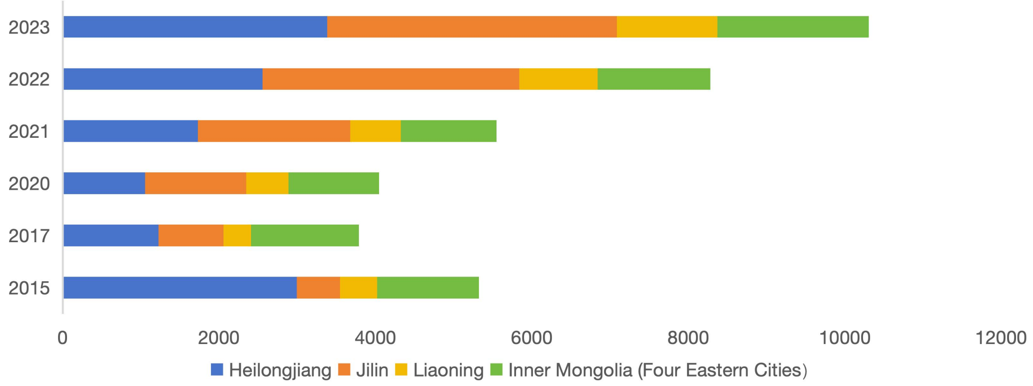


Figure 7 - Area of black soil in Northeast China under conservation tillage （Unit:khm^2）

Source: China Rural Statistical Yearbook

Despite the progress made with conservation tillage in the Northeast, challenges remain in the widespread adoption of the technology and the promotion of necessary equipment. The vast and diverse landscape of the Northeast, with its complex terrain, means that ecological conditions can vary significantly even within the same county or township. A one-size-fits-all approach to promoting conservation tillage may not meet the specific needs of different areas(AO et al., 2021). Moreover, the dissemination of machinery, particularly high-performance no-till seeders and other advanced equipment, has been relatively slow. Some areas still struggle to access this equipment, and the high cost of these machines poses a financial burden for farmers with limited economic resources(CAS, 2021).

In the face of these challenges, agricultural technological innovation and emerging entrepreneurial opportunities are bringing new impetus to developing conservation tillage. Firstly, based on the unique climatic conditions in the Northeast, agri-tech enterprises can develop no-till machinery and intelligent tillage equipment that are more adapted to the local climate and soil characteristics. This will improve the efficiency of conservation tillage, and reduce equipment costs for farmers, thus promoting the further popularisation of the technology(AO et al., 2021). Additionally, entrepreneurial opportunities in the agricultural services sector are emerging, particularly in technology promotion and equipment leasing. Providing modern agricultural equipment rental services or offering technical training to help farmers master advanced farming techniques could become key entrepreneurial directions(Chen et al., 2022). These ventures would promote conservation tillage and create new employment opportunities, fostering the diversification of the rural economy.

More importantly, national-level scientific projects such as the Black Soil Granary project led by the Chinese Academy of Sciences, are driving the establishment of regional agricultural innovation models(CAS, 2022). Particularly in the conservation and efficient use of black soil, these innovative models help farmers adapt to local ecological conditions and achieve sustainable agricultural development. And through the introduction of big data and smart agriculture technology, the modernisation of agricultural production is further enhanced(AO et al., 2021). In the future, with further innovation and optimisation of conservation tillage technologies, agricultural productivity in the Northeast is expected to continue to improve, making a greater contribution to China's food security and rural economic development.

Regional Innovation Model	Impact
Lishu Model 2.0 + Longjiang Model	Supports the implementation of the National Black Soil Protection Project
Da'an Model	A combination of efficient improvement and comprehensive utilisation of saline-alkali land
Dahuawan Model	Big data and intelligent equipment as the core High integration of information technology and agricultural technology
"Black Soil Granary" Science and Technology Campaign	Established an integrated monitoring and sensing system for space and ground "Geography + Big Data + Modern Agriculture" model of the "Black Soil Granary" full-region customisation model

Table 13 - Regional Agricultural Innovation Model for Black Soil Protection and the Significance
Source: (CAS,2021)

In summary, the widespread application of conservation tillage in Northeast China has far-reaching significance in improving soil quality, increasing agricultural productivity and farmers' income. Although there are still some challenges in the promotion of equipment and the spread of the technology, through continued innovation in agricultural innovation and the expansion of entrepreneurial opportunities. Conservation tillage is expected to continue to play an important role in the future, providing solid support for the sustainable development of agriculture and the prosperity of the rural economy.

5.1.2 Water-Saving Irrigation and Water Resource Management in Arid Western Regions

Irrigated agriculture in China contributes to 75% of the nation’s total agricultural output value, which is crucial for food security and poverty reduction. However, irrigation consumes over 60% of the country's total water usage, making it one of the main causes of water stress in China (World Bank, 2019) The challenges of population growth, rapid industrialisation, and climate change have further exacerbated water resource problems. The arid inland river basins of Northwest China, with their dry climate, scarce precipitation, and extremely limited water resources. Excessive groundwater extraction and severe land desertification highlight the urgent need for technological improvements and policy support to address these issues(Yue et al.,2016).

In this context, China has introduced a series of policies to support the development of water-saving technologies in agriculture. Currently, water-saving irrigation technologies such as drip irrigation, micro-irrigation, and water-fertilizer integration have become an important means for the Western region to solve water shortages and improve agricultural productivity. These technologies have greatly improved water use efficiency and crop yields by precisely supplying water and reducing evaporation losses and ineffective water consumption(Yue et al.,2016). The continuous promotion of water-saving irrigation projects in the western region has created good conditions for the modernization and intensive development of agriculture(Jiang and Wang, 2019). For example, in the Hotan region of Xinjiang, the large-scale application of mulch drip irrigation has enabled the realisation of land transfer and large-scale operation. It not only improves water-saving effects, but also promotes the development of modern agriculture(Wang et al., 2016). In addition, the shallow-buried drip irrigation project in Kezuozhong Banner, Inner Mongolia, has not only improved productivity, but also promoted the growth of farmers' non-farm income, increasing the per capita income of farmers by about 2,300 yuan(Hengshan et al., 2023)The widespread application of water-saving irrigation effectively alleviates the problem of water wastage under traditional irrigation methods. Research indicates that improvements in irrigation water utilisation efficiency and grain productivity have made a significant contribution to the economies of rural areas in the West. The World Bank's Water Conservation Project has improved agricultural water management through new or upgraded irrigation infrastructure, reaching nearly 600,000 beneficiaries and effectively raising the incomes of poor farmers(World Bank, 2019).

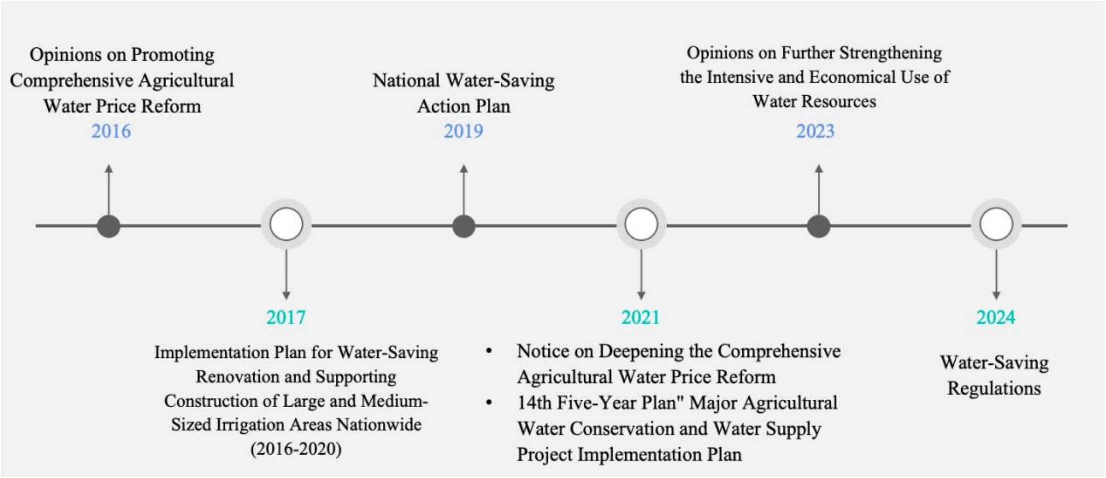


Figure 8 - Policies and Documents Related to Water Conservation in Agriculture

Source: Self-Made

Despite the notable success of water-saving irrigation in the Western regions, it also faces many challenges. The high initial investment costs of water-saving irrigation systems, such as drip irrigation, make them unaffordable for many farmers, particularly those with limited financial resources(Li, 2006). Additionally, the promotion of these technologies faces technical and infrastructural limitations. In some areas, geographical conditions and inadequate technological support, hinder the development of the water-saving industry(Yue et al.,2016). Furthermore, the current lack of standardised, intelligent water-saving technology models suited to different regions and crops constrains the effective development of the water-saving industry(Li, 2006).

These challenges also present opportunities for innovation in water-saving irrigation. Smart irrigation systems and sustainable water resource management solutions are emerging at the forefront of this field(Obaideen et al., 2022). By incorporating big data, sensor networks, and artificial intelligence technologies, farmers and water resource managers can better monitor soil moisture, weather conditions, and water usage. It enables real-time adjustments to irrigation plans and optimising water resource utilisation(Yue et al.,2016). These intelligent systems can enhance irrigation efficiency and reduce human error and resource wastage, making them particularly suitable for the complex climate conditions of the Western regions.

Simultaneously, the advancement of technology is opening up new entrepreneurial opportunities in agricultural water resource management. Data-driven water monitoring and management platforms provide local governments and farmers with accurate water allocation and management solutions to optimise agricultural water usage(Obaideen et al., 2022). Entrepreneurs can capitalise on this demand by developing specialised water management applications and platforms that provide customised solutions to improve water use efficiency across various regions. In addition, by partnering with local governments, such entrepreneurial projects can be scaled up with policy support. And then it can further promote the popularisation of water-saving irrigation technologies and intelligent water management. In recent years, China has built a number of new national laboratories for the efficient use of agricultural water resources(Obaideen et al., 2022). And through national key R&D projects, China has successfully developed the world's largest area of application of sub-film drip irrigation and shallow-buried drip irrigation water-fertiliser integration technologies. These innovations provide the technical foundation for large-scale water conservation, fertiliser reduction, and increased grain production.

Additionally, other water resource management initiatives have also yielded significant results. The chart shows multiple achievements in efficient water resource management. The area of water-saving irrigation has steadily increased and remained high after 2021, indicating that the promotion of water-saving technologies has achieved significant success. Meanwhile, the area of water logging control has remained stable, possibly suggesting that efforts in this field have reached saturation or are facing resource constraints. And with their combined efforts, the area of erosion control has steadily increased, demonstrating continued progress and effective outcomes.

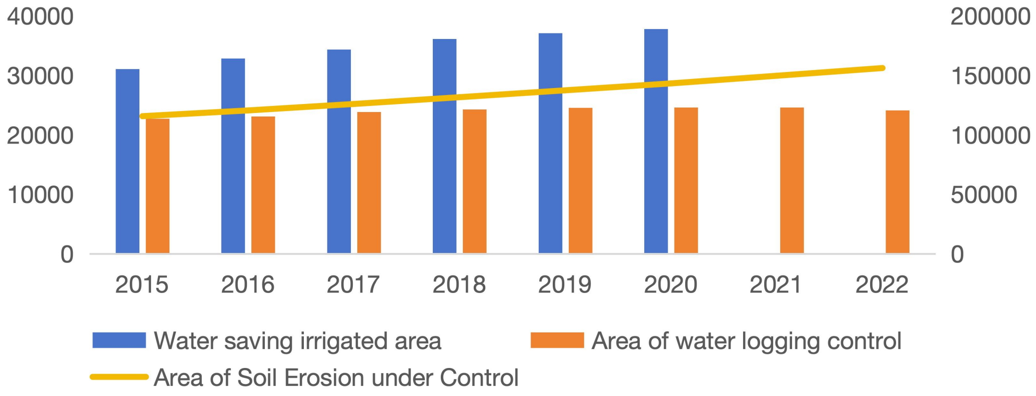


Figure 9 - Area of Efficient Water Management（Unit:khm^2）
Source:China Rural Statistical Yearbook

Overall, water-saving irrigation and water resource management in the Western regions has been remarkably effective in contributing to the modernisation of agriculture and raising the incomes of rural residents. Although challenges remain in terms of funding, technology, and equity, innovations in smart, data-driven water-saving irrigation and water resource management offer new pathways and entrepreneurial opportunities in this field. With continued technological advancements and policy support, strengthening innovation and the development of the water-saving industry will provide stronger momentum for sustainable agricultural development in the Western regions.

5.1.3 Comprehensive Utilisation of Livestock and Poultry Manure in China

The comprehensive utilisation of livestock and poultry manure has shown significant positive economic benefits across all four economic regions. This technology's implementation has notably increased farmers' incomes and improved environmental quality, regardless of whether the region is economically developed or underdeveloped.

The promotion of comprehensive livestock and poultry manure utilisation technologies has achieved significant results, with the promotion of biogas projects showing initial success in some provinces. Through anaerobic fermentation technology, livestock and poultry manure and other organic wastes are converted into biogas, a clean energy source that can be used for power generation, heating or alternative fuels. The by-products of biogas fermentation—digestate and biogas slurry—are also widely used in agricultural production as efficient organic fertilisers(Gao et al., 2019). By 2022, the number of biogas projects nationwide had reached 75,115. Hunan Province and Guangdong Province were particularly prominent, with 10,937 and 15,174 projects respectively(NBSC, 2023). These initiatives have significantly enhanced both farmers' economic benefits and environmental quality, reflecting the potential of manure processing for fertiliser and energy production. However, there are still challenges such as imperfect policies and regulations, outdated technology and equipment, as well as insufficient capital investment. In particular, some regions face slow infrastructure development and technology adoption, with a lack of intelligent and standardised processing models(Varma et al., 2021).

As a result, The future of manure management lies in developing intelligent and efficient processing systems that utilise advanced equipment and data monitoring technologies. These innovations enable farmers and businesses to precisely control the treatment process, reducing environmental impact and maximising resource utilisation. The introduction of new feeding techniques and manure processing equipment, along with the widespread adoption of these technologies, will not only drive the sustainable development of the livestock industry but also create new business opportunities(Gaballah et al.,2021). As more companies invest in innovative environmental protection technologies, the resource utilisation of livestock and poultry manure will continue to improve. Entrepreneurs in this field can further accelerate industry upgrades and promote green development by offering manure processing technology services, equipment leasing, and consultancy(Varma et al., 2021).

Overall, the promotion of livestock and poultry manure utilisation technologies has not only improved agricultural efficiency but also significantly enhanced environmental quality. Despite challenges related to policy, technology, and funding, the industry has promising prospects with continued technological innovation and policy support.

5.2 CSA Impact on Carbon Emissions

Climate-Smart Agriculture mitigates agricultural carbon emissions by targeting the primary sources of emissions, such as fertiliser application, plastic film usage, diesel consumption, pesticide application, tillage, and irrigation. These sources are traditionally significant contributors to the overall carbon footprint of agricultural activities. CSA practices, however, provide innovative solutions that both reduce emissions and promote sustainability.

For instance, by employing precision farming techniques, CSA optimises fertiliser use. It ensures that crops receive only the nutrients they need, thereby reducing excess fertiliser application and its associated emissions(Rajet al., 2022). Similarly, the shift from conventional plastic films to biodegradable alternatives or the reduction of plastic use through efficient water management techniques helps in lowering the carbon emissions linked to plastic film application(Huang et al., 2019). Besides, the adoption of renewable energy sources, such as solar-powered irrigation systems and electric machinery, replaces diesel consumption, which is a major source of carbon emissions in traditional farming. Furthermore, integrated pest management (IPM) techniques reduce the reliance on chemical pesticides, which are carbon-intensive in both production and application, leading to lower emissions(Dara, 2019).

In different regions of China, CSA demonstrates distinct characteristics in reducing agricultural carbon emissions(Huang et al., 2019). In the Northeast, conservation tillage has effectively enhanced soil carbon sequestration, thereby reducing emissions. In the Western regions, the promotion of water-saving irrigation systems, such as drip and sprinkler irrigation, not only conserves water but also reduces the energy required for irrigation, significantly lowering emissions associated with traditional, energy-intensive methods. Furthermore, the utilisation of livestock manure, particularly through biogas projects, reduces energy use and greenhouse gas emissions, while the application of digestate as organic fertiliser further enhances soil carbon sequestration. In the more industrialised Eastern and Central regions, where carbon emissions are relatively higher, efforts are being made to manage carbon footprints through technological innovation and improved resource efficiency(Huang et al., 2019). By reducing emissions and reliance on fossil fuels, CSA technologies not only enhance agricultural sustainability but also support China’s carbon neutrality goals, making a significant contribution to the nation’s overall carbon neutrality efforts.

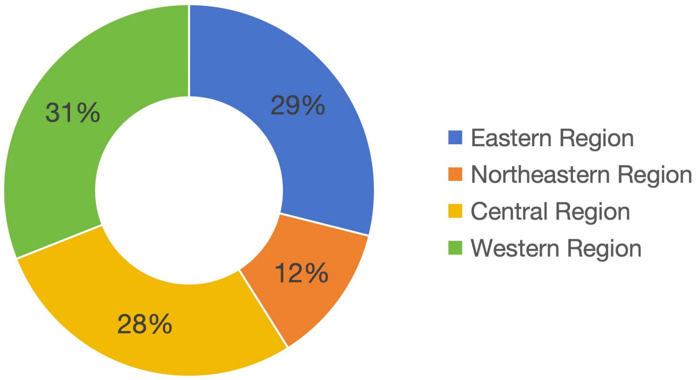


Figure 10- Agriculture Carbon Emission in Different Regions （Unit:1000tons）
Source: China Rural Statistical Yearbook

In the meantime, the development of carbon markets and the potential business models around carbon-sequestration agriculture present new opportunities for sustainable agricultural development(Hua and Dong, 2019). Through CSA technologies, agriculture can not only reduce carbon emissions but also generate economic returns by participating in carbon trading markets. Entrepreneurs can develop carbon trading platforms and provide carbon sink agriculture certification services to farmers and enterprises to help them profit from the carbon market(Zhou and Li, 2019). Additionally, services related to manure management, biogas project development, and consulting offer significant potential for agricultural innovation and green entrepreneurship(Hua and Dong, 2019). These innovative initiatives will drive the decarbonisation of agriculture while creating new economic growth opportunities for farmers and businesses, leading to both environmental and economic benefits.

5.3 The impact of CSA on sustainable innovation in China

The implementation of CSA across various regions in China has had a significant combined impact on the rural economy, farmers' incomes, and environmental protection. The integration of CSA with sustainable innovation has created promising opportunities for the dual advancement of agricultural technology and ecological conservation. The expansion of smart agricultural technologies, the development of carbon-sequestration agriculture, and the emergence of green agriculture-based entrepreneurial opportunities are continually broadening this landscape. For instance, technologies such as smart irrigation systems, soil monitoring devices, and digital farm management tools not only enhance productivity but also promote ecological conservation by reducing resource waste. Moreover, renewable energy projects like biogas, have fostered the use of clean energy and generated new economic opportunities in rural areas. Each region, due to its unique resource endowments and climatic conditions, has demonstrated distinct potential for agricultural technology entrepreneurship, especially in fields such as smart agriculture, sustainable development services, and green agricultural supply chains, leading to a series of innovative projects that drive sustainable rural economic development.

The rural entrepreneurship index further shows the varied capacity for innovation across China's regions. Eastern region, where the index is notably higher, have emerged as leaders in the adoption and innovation of CSA technologies. This higher entrepreneurship index in the east reflects a more dynamic and resource-rich environment where smart agriculture and green supply chains are flourishing. These regions benefit from better infrastructure, access to capital, and stronger market connections, enabling them to make use of CSA practices and drive sustainable agricultural innovation. This concentration of entrepreneurial activity shows the need for targeted interventions in less-developed regions to balance these gaps and ensure that all areas can benefit equally from CSA-driven advancements.

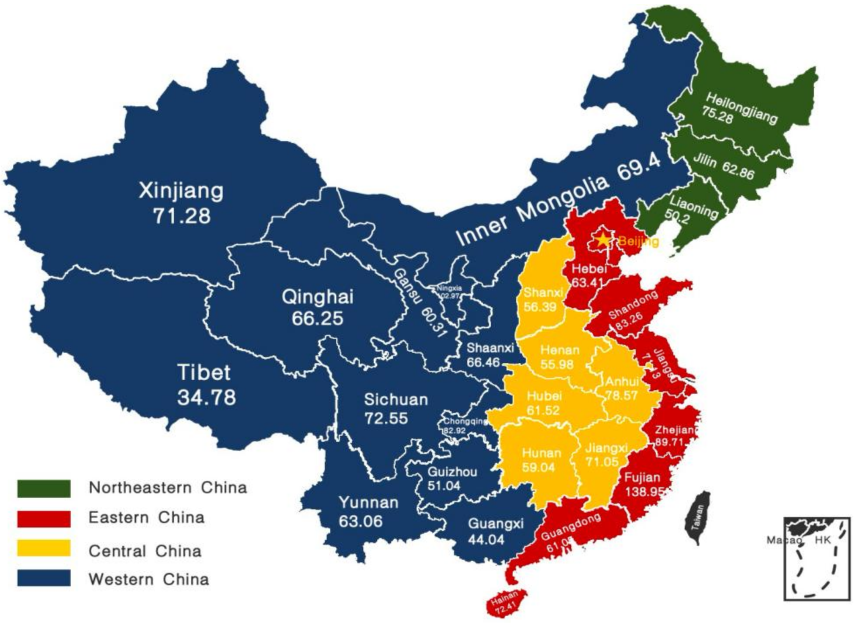


Figure 11 - China Rural Innovation and Entrepreneurship Index by Province in2021
Source:(Ruan et al., 2023)

There is no doubt that rising levels of education are conducive to promoting innovation and entrepreneurship in rural areas. The recent trends in rural education, showing a decline in primary and middle school enrollments but an increase in high school enrollments, indicate a shift towards a more educated rural population. This shift is particularly important because the higher the level of education, the greater the capacity to adopt and innovate within the CSA framework. Educated farmers and young rural entrepreneurs are more likely to understand and implement complex technologies like precision farming and renewable energy systems(Vecchioet al., 2020), which are essential for both improving agricultural productivity and ensuring environmental sustainability.

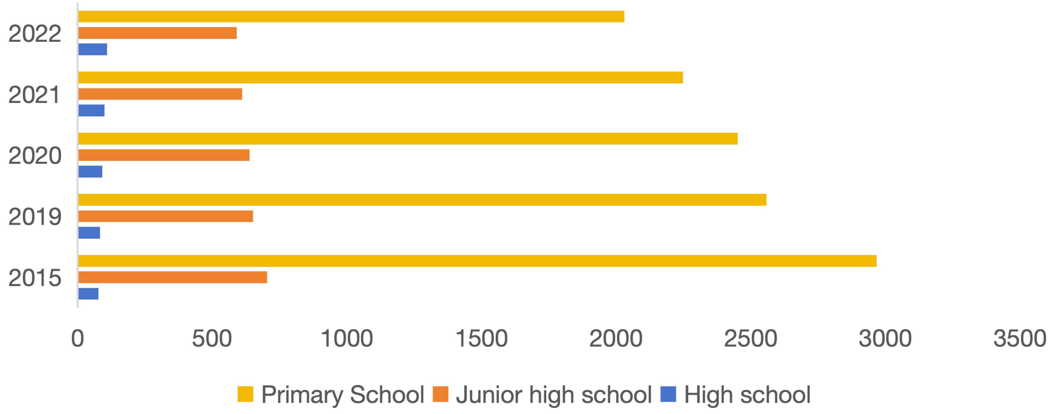


Figure 12 - Number of Students Enrolled in Rural China（Unit:10,000 people）
Source:China Rural Statistical Yearbook

In addition, increased levels of education are expected to further boost innovation in regions where entrepreneurship is booming, especially in the East. However, to realise the full potential of CSA technologies in all regions, it is important to invest in education and entrepreneurship support in the Central and Western regions. By strengthening education and providing targeted support to rural entrepreneurs, these regions can increase their capacity for sustainable innovation and ensure that the benefits of CSA are more equitably distributed across China.

In conclusion, this chapter has discussed the significant impact of CSA on sustainable innovation and agricultural economic development in rural China. By analysing the implementation of CSA across different economic regions, it has evaluated both its economic and environmental benefits, providing suggestions for sustainable innovation in rural areas. Furthermore, the discussion has highlighted the critical role of education and entrepreneurship in driving the application and innovation of CSA technologies. By addressing regional disparities and developing targeted carbon management strategies, CSA practices have not only enhanced agricultural sustainability but also provided practical avenues for rural areas to contribute positively to national and global environmental goals. The continued promotion and optimisation of CSA technologies holds profound significance.

Chapter 6 - Conclusion

This study provides a comprehensive analysis of the promotion of Climate-Smart Agriculture across different regions in China, exploring its multifaceted impacts on rural incomes, agricultural economic development, and environmental sustainability. The results of the study provide strong empirical evidence that CSA has a significant positive effect on improving farmers' income and promoting sustainable agricultural development in China. By examining the specific impacts of CSA technologies across various regions, this study explores how technological innovation can drive agricultural economic growth, and demonstrates the role of CSA in the global response to climate change. These insights are valuable for policymakers and practitioners, offering guidance for the continued diffusion and optimisation of CSA technologies. With the continuous improvement and diffusion of CSA technologies, China is expected to further promote agricultural modernisation and green transformation, and make more contributions to achieve global sustainable development goals.

During this research, the first question addressed was: "**How does Climate-Smart Agriculture technology impact the rural economy in China?**" The study found that CSA technologies, such as conservation tillage, water-saving irrigation, and integrated livestock waste management, significantly enhance agricultural productivity in different regions. For example, the application of conservation tillage technology in the Northeast improved soil quality and increased grain yields. Similarly, water-saving irrigation technologies have effectively optimised water use, increased crop yields and reduced agricultural production costs in the arid western region. In addition, the comprehensive use of livestock and poultry manure not only reduces environmental pollution but also creates new sources of income for farmers by converting waste into organic fertiliser and clean energy. The combined application of these technologies has significantly enhanced farmers' profitability and improved overall agricultural productivity. Overall, the current CSA technologies have wide applicability in different economic regions and play a key role in promoting sustainable rural economic development.

Regarding the second research question: "**What potential opportunities for sustainable entrepreneurship and innovation are created by CSA practices?**" The study indicates that the spread of CSA technologies has not only improved traditional agricultural production models, but has also spawned new agricultural entrepreneurial opportunities, particularly the smart agriculture, green supply chain management and renewable energy sectors. The widespread use of smart irrigation systems, precision fertilization technologies, and modern machinery enables farmers to manage agricultural production more precisely. This improves efficiency, reduces resource wastage and generates direct economic benefits. Moreover, the adoption of these technologies has stimulated innovation and entrepreneurial activities in related fields such as agricultural technology services, equipment leasing, and agricultural consulting. It is worth noting that the level of education plays a key role in this process. Well-educated farmers and rural entrepreneurs are better equipped to understand and apply complex agricultural technologies, such as the IoT, big data analysis, and artificial intelligence, and are thus more effective at innovative entrepreneurship. Improved education also encourages more young people to stay in or return to the countryside to start their own businesses(Vecchioet al., 2020). These people can use advanced technologies and management concepts to drive the diversification and modernisation of the rural economy. At the same time, education enhances the adaptability of farmers and entrepreneurs. It enables them to respond flexibly to market changes and policy adjustments, seize market opportunities, invest in environmental technologies, or create new green business models. Such adaptability and innovation are key factors in promoting sustainable entrepreneurship and achieving rural economic transformation(Schaltegg et al., 2016).

Finally, in response to the question "**How do these practices contribute to carbon reduction, environmental sustainability and the achievement of related sustainable development goals?**", the study found that CSA technologies effectively contribute to environmental sustainability in several ways. First, they reduce the use of fertilisers and pesticides, thereby decreasing chemical emissions from agricultural production. Precision fertiliser application techniques enable farmers to apply fertilisers more accurately to meet the actual needs of their crops, reducing excessive application and the associated carbon emissions. Meanwhile, using integrated pest management (IPM) methods reduces pesticide use, further lowering the chemical burden on the environment from agricultural production. These measures not only reduce greenhouse gas emissions but also improve soil and water ecological quality. Besides, through conservation tillage and soil improvement measures, CSA technologies significantly increase the carbon sequestration capacity of soils. It enables agricultural production to absorb more carbon dioxide and slow the accumulation of greenhouse gases. Furthermore, CSA practices have significantly reduced the use of diesel fuel by promoting energy-efficient agricultural machinery and new energy equipment, such as electric farm machinery, thereby reducing carbon emissions from the operation of agricultural machinery. Particularly in the irrigation process, where traditional irrigation methods often consume large amounts of energy, the application of water-saving irrigation technologies not only saves water, but also reduces the energy consumption required for irrigation. It in turn reduces the carbon emissions associated with irrigation. This combination of energy- and water-saving technological practices is important for improving the environmental performance of agricultural production. These practices reduce greenhouse gas emissions and enhance environmental sustainability. And they further advance the green transformation of Chinese agriculture and contribute to multiple SDGs, including climate action, responsible consumption and production, and zero hunger.

Despite the valuable findings of this study, there are certain limitations. Firstly, the regional categorisation in the study was mainly based on the economic level and failed to adequately consider other important factors such as crop type, climatic conditions, soil type, and water availability. This single-dimensional regional classification may limit the broader applicability of the study's findings. Different crops have varying requirements for agricultural technologies. For example, rice-growing areas rely on irrigation technologies much more than dry-crop areas. And differences in climatic conditions, such as temperature and precipitation, may also affect the effectiveness of CSA technologies(Hussai et al., 2022). In addition, the diversity of soil types may lead to different effects of the same soil improvement technology in different areas. Given China's vast size and significant regional differences in economic development levels, climate conditions, and resource endowments, the promotion and implementation of CSA yield different outcomes across regions(Brussaard et al., 2007). For example, the cold climate in Northeast China might affect the effectiveness of certain CSA technologies, while the arid western regions have a stronger demand for water-saving technologies. These regional variations may result in study findings that do not fully reflect the actual effectiveness of CSA technologies nationwide.

Second, this study fails to fully explore the long-term impacts of CSA technologies. Due to the relatively short time span of the research, this study mainly focuses on the initial effects of CSA technologies on agricultural productivity and environmental sustainability(Aziz, Mahmood and Islam, 2013). However, it may take a longer time for the application of CSA technologies in agriculture to reveal their full ecological and economic benefits. For instance, improvements in soil quality, increased carbon sink capacity, and significant increases in farmers' incomes may take years or even longer to be fully verified. As a result, the study results may only reflect the preliminary outcomes of CSA technology applications, without a full assessment of the long-term effects. Such time constraints may lead to an inadequate understanding of the long-term benefits of CSA.

In addition, although this study partially examined the impact of natural disasters on agricultural productivity by considering the area of crops affected by the disaster through control variables in the empirical analyses, there are still some other important external factors that could not be fully examined. For example, while crop disaster areas can reflect the impact of natural disasters to some extent, specific disaster types (e.g., floods, droughts, hailstorms) and their frequency and intensity might differently affect the implementation of CSA technologies(Sisay et al., 2023). Furthermore, policy changes, such as adjustments in agricultural subsidies or the strengthening of environmental protection policies, might alter farmers' acceptance and reliance on CSA technologies. Due to the limitations in the scope and data of the study, these complex external variables were not fully considered in the research design, which might limit the interpretation of the study's results(Sisay et al., 2023). Therefore, future research should pay more attention to the diversity of these external factors and their potential impacts, to ensure broader applicability and accuracy of the research findings.

Therefore, to gain a more comprehensive understanding of the effects of CSA technology, future research should expand in the following areas. Firstly, future studies should consider more comprehensive categorisation criteria, incorporating multi-dimensional regional characteristics to enhance the applicability and accuracy of the findings. Second, extending the period of research is recommended to assess the long-term impacts and benefits of CSA technologies fully. Lastly, future studies should pay more attention to the diversity of these external factors and their potential impacts to ensure broader applicability and accuracy of the findings. These extensions will help to more accurately assess the true potential and limitations of CSA technologies and provide a stronger theoretical foundation and practical guidance for sustainable agricultural development in China and globally.

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Appendices

Appendix 1- 2015-2022 CSA Practices (independent variable) in Different Provinces in China

Note: Provinces are indicated by the province code, and “Pro” is a division by economic region, where 1 represents the Northeast, 2 the East, 3 the Central, and 4 the West.

year	Province code	Pro	Area of Conservation tillage (khm^2)	Water saving irrigated area (khm^2)	Comprehensive utilization rate of livestock and poultry manure (%)
year	Province code	Pro	AOCT	WSIA	CUOL
2015	23	1	2990	1,696.85	21.59
2016	23	1	2317.93	1,975.39	21.84
2017	23	1	1255	2,086.61	23.14
2018	23	1	781.42	2,150.97	25.02
2019	23	1	958.13	2,200.42	24.98
2020	23	1	1050.84	2,198.40	25.48
2021	23	1	1724.76	2,196.38	25.92
2022	23	1	2398.68	2,194.36	27.28
2015	22	1	551.38	668.75	13.04
2016	22	1	695.09	688.63	13.97
2017	22	1	829.03	758.77	14.24
2018	22	1	924.5	800.60	14.22
2019	22	1	1046.35	821.10	15.38
2020	22	1	1294.16	826.02	15.23
2021	22	1	1949.69	830.94	14.86
2022	22	1	2605.22	835.86	15.62
2015	21	1	475.23	806.46	22.26
2016	21	1	432.91	884.06	23.87
2017	21	1	353.44	929.58	23.40
2018	21	1	286.02	968.00	24.81
2019	21	1	318.53	967.75	25.06
2020	21	1	538.67	973.78	25.64
2021	21	1	646.28	979.81	26.50
2022	21	1	753.89	985.84	27.61
2015	13	2	290.19	3,139.98	22.00
2016	13	2	179.05	3,314.24	23.35
2017	13	2	134.54	3,415.72	24.40
2018	13	2	146.19	3,591.43	24.62
2019	13	2	168.6	3,623.91	25.92

2020	13	2	149.24	3,648.92	25.55
2021	13	2	173.02	3,673.93	26.48
2022	13	2	196.8	3,698.94	27.30
2015	32	2	104.42	2,336.09	21.61
2016	32	2	88.91	2,422.57	21.15
2017	32	2	81.15	2,637.47	22.55
2018	32	2	585.16	2,767.23	22.60
2019	32	2	273.66	2,847.75	23.90
2020	32	2	48.28	2,885.25	24.75
2021	32	2	211.54	2,922.75	25.23
2022	32	2	374.80	2,960.25	25.98
2015	35	2	0	575.17	21.39
2016	35	2	0	618.10	21.01
2017	35	2	0	657.88	22.00
2018	35	2	168.52	700.53	23.12
2019	35	2	161.23	703.19	23.79
2020	35	2	96.62	717.16	23.93
2021	35	2	97.44	731.13	23.77
2022	35	2	98.26	745.10	24.61
2015	37	2	1196.69	2,919.31	20.98
2016	37	2	1282.08	3,049.12	20.75
2017	37	2	1230.7	3,213.21	22.47
2018	37	2	1213.68	3,372.32	22.40
2019	37	2	1223.26	3,465.01	22.92
2020	37	2	1235.47	3,569.30	25.36
2021	37	2	1009.46	3,673.59	24.34
2022	37	2	783.45	3,777.88	25.96
2015	44	2	0.05	295.86	23.12
2016	44	2	0.02	301.49	23.50
2017	44	2	0.02	326.19	23.96
2018	44	2	0.17	418.22	24.69
2019	44	2	0.02	425.05	25.02
2020	44	2	0.17	428.75	25.76
2021	44	2	0.15	432.45	26.27
2022	44	2	0.13	436.15	27.18
2015	14	3	679.12	895.44	13.62
2016	14	3	684.48	909.14	14.07
2017	14	3	645.96	810.98	13.92
2018	14	3	567.31	968.00	14.76
2019	14	3	540.42	995.46	15.02
2020	14	3	548.18	1,013.38	15.68

2021	14	3	531.91	1,031.30	15.27
2022	14	3	515.64	1,049.22	16.21
2015	34	3	105.82	906.89	13.69
2016	34	3	86.2	943.75	13.99
2017	34	3	78.37	976.00	14.68
2018	34	3	91.66	1,025.27	14.52
2019	34	3	93.97	1,059.81	15.19
2020	34	3	96.62	1,100.45	16.03
2021	34	3	97.66	1,141.09	16.17
2022	34	3	374.80	1,181.73	16.12
2015	36	3	5.96	500.34	13.18
2016	36	3	5.69	524.96	14.23
2017	36	3	5.69	544.66	13.94
2018	36	3	17.17	595.61	14.93
2019	36	3	14.53	630.91	13.95
2020	36	3	4.38	680.52	15.22
2021	36	3	4.61	730.13	15.33
2022	36	3	4.84	779.74	15.49
2015	41	3	491.94	1,672.16	13.55
2016	41	3	512.65	1,806.61	13.95
2017	41	3	534.97	1,893.27	13.80
2018	41	3	618.67	1,997.86	14.69
2019	41	3	574.73	2,190.19	15.62
2020	41	3	628.64	2,293.00	14.98
2021	41	3	578.98	2,395.81	15.20
2022	41	3	529.32	2,498.62	16.44
2015	42	3	72.42	383.22	21.05
2016	42	3	77.91	407.62	22.00
2017	42	3	80.65	443.98	22.14
2018	42	3	227.27	488.53	22.28
2019	42	3	530.35	562.00	23.66
2020	42	3	430.52	594.65	24.79
2021	42	3	506.83	627.30	24.77
2022	42	3	583.14	659.95	25.55
2015	43	3	72.42	348.18	21.43
2016	43	3	41.47	358.19	21.63
2017	43	3	41.09	395.41	22.41
2018	43	3	41.68	431.05	23.34
2019	43	3	46.1	452.05	24.21
2020	43	3	44.4	472.18	23.04
2021	43	3	46.33	492.31	25.00

2022	43	3	48.26	512.44	25.74
2015	15	4	1301.81	2,474.79	5.98
2016	15	4	1342.4	2,638.65	5.99
2017	15	4	1379.13	2,800.44	6.05
2018	15	4	1394.55	2,925.95	6.15
2019	15	4	1158.41	2,931.92	6.40
2020	15	4	1160.79	2,931.61	6.45
2021	15	4	1221.89	2,931.30	6.71
2022	15	4	1282.99	2,930.99	6.55
2015	51	4	24.79	1,567.89	13.70
2016	51	4	25.19	1,639.79	13.69
2017	51	4	25.61	1,702.60	14.55
2018	51	4	194.52	1,762.71	14.32
2019	51	4	123.38	1,793.03	14.98
2020	51	4	123.57	1,829.58	15.76
2021	51	4	32.71	1,866.13	16.05
2022	51	4	22.37	1,902.68	16.50
2015	61	4	404.11	877.22	21.26
2016	61	4	360.34	906.88	21.92
2017	61	4	345.99	931.49	22.70
2018	61	4	516.87	965.52	22.45
2019	61	4	401.94	971.29	23.01
2020	61	4	389.73	988.07	23.99
2021	61	4	394.5	1,004.85	24.78
2022	61	4	399.27	1,021.63	25.45
2015	53	4	1.49	724.51	5.92
2016	53	4	1.76	794.26	6.18
2017	53	4	2.94	867.97	6.05
2018	53	4	13.68	941.18	6.24
2019	53	4	93.69	959.91	6.36
2020	53	4	81.19	1,001.68	6.61
2021	53	4	144.67	1,043.45	6.44
2022	53	4	208.15	1,085.22	6.71
2015	62	4	140.97	920.67	21.21
2016	62	4	132.94	976.22	22.19
2017	62	4	132.12	1,020.89	22.57
2018	62	4	126.08	1,066.21	23.82
2019	62	4	129.01	1,058.74	23.75
2020	62	4	118.01	1,083.01	24.41
2021	62	4	108.24	1,107.28	25.17
2022	62	4	98.47	1,131.55	26.10

2015	65	4	113.42	3,671.93	5.93
2016	65	4	91.72	3,890.92	5.95
2017	65	4	78.27	3,996.20	6.20
2018	65	4	114.36	4,088.84	6.11
2019	65	4	89.55	4,247.83	6.23
2020	65	4	87.96	4,333.31	6.65
2021	65	4	110.1	4,418.79	6.26
2022	65	4	132.24	4,504.27	6.75

Appendix 2- 2015-2022 Rural Residents Income and Consumption Expenditure (dependent variable) in Various Provinces in China

year	Province code	Pro	Per Capita Disposable Income of rural household(yuan)	Per Capita Consumption Expenditure of Rural Households(yuan)
year	Province code	Pro	DI	REPC
2015	23	1	11,095	8,391
2016	23	1	11,832	9,424
2017	23	1	12,665	10,524
2018	23	1	13,804	11,417
2019	23	1	14,982	12,495
2020	23	1	16,168	12,360
2021	23	1	17,889	15,225
2022	23	1	18,577	15,162
2015	22	1	11,326	8,783
2016	22	1	12,123	9,521
2017	22	1	12,950	10,279
2018	22	1	13,748	10,826
2019	22	1	14,936	11,457
2020	22	1	16,067	11,864
2021	22	1	17,642	13,411
2022	22	1	18,134	12,729
2015	21	1	12,057	8,873
2016	21	1	12,881	9,953
2017	21	1	13,747	10,787
2018	21	1	14,656	11,455
2019	21	1	16,108	12,030
2020	21	1	17,450	12,311
2021	21	1	19,217	14,606
2022	21	1	19,908	14,326
2015	13	2	11,051	9,023
2016	13	2	11,919	9,798
2017	13	2	12,881	10,536
2018	13	2	14,031	11,383
2019	13	2	15,373	12,372
2020	13	2	16,467	12,644
2021	13	2	18,179	15,391
2022	13	2	19,364	16,271
2015	32	2	16,257	12,883

2016	32	2	17,606	14,428
2017	32	2	19,158	15,612
2018	32	2	20,845	16,567
2019	32	2	22,675	17,716
2020	32	2	24,198	17,022
2021	32	2	26,791	21,130
2022	32	2	28,486	22,597
2015	35	2	13,793	11,961
2016	35	2	14,999	12,911
2017	35	2	16,335	14,003
2018	35	2	17,821	14,943
2019	35	2	19,568	16,281
2020	35	2	20,880	16,339
2021	35	2	23,229	19,290
2022	35	2	24,987	20,467
2015	37	2	12,930	8,748
2016	37	2	13,954	9,519
2017	37	2	15,118	10,342
2018	37	2	16,297	11,270
2019	37	2	17,775	12,309
2020	37	2	18,753	12,660
2021	37	2	20,794	14,299
2022	37	2	22,110	14,687
2015	44	2	13,360	11,103
2016	44	2	14,512	12,415
2017	44	2	15,780	13,200
2018	44	2	17,168	15,411
2019	44	2	18,818	16,949
2020	44	2	20,143	17,132
2021	44	2	22,306	20,012
2022	44	2	23,598	20,800
2015	14	3	9,454	7,421
2016	14	3	10,082	8,029
2017	14	3	10,788	8,424
2018	14	3	11,750	9,172
2019	14	3	12,902	9,728
2020	14	3	13,878	10,290
2021	14	3	15,308	11,410
2022	14	3	16,323	12,091
2015	34	3	10,821	8,975
2016	34	3	11,720	10,287

2017	34	3	12,758	11,106
2018	34	3	13,996	12,748
2019	34	3	15,416	14,546
2020	34	3	16,620	15,024
2021	34	3	18,372	17,163
2022	34	3	19,575	17,980
2015	36	3	11,139	8,486
2016	36	3	12,138	9,128
2017	36	3	13,242	9,870
2018	36	3	14,460	10,885
2019	36	3	15,796	12,497
2020	36	3	16,981	13,579
2021	36	3	18,684	15,663
2022	36	3	19,936	16,984
2015	41	3	10,853	7,887
2016	41	3	11,697	8,587
2017	41	3	12,719	9,212
2018	41	3	13,831	10,392
2019	41	3	15,164	11,546
2020	41	3	16,108	12,201
2021	41	3	17,533	14,073
2022	41	3	18,697	14,824
2015	42	3	11,844	9,803
2016	42	3	12,725	10,938
2017	42	3	13,812	11,633
2018	42	3	14,978	13,946
2019	42	3	16,391	15,328
2020	42	3	16,306	14,472
2021	42	3	18,259	17,647
2022	42	3	19,709	18,991
2015	43	3	10,993	9,691
2016	43	3	11,930	10,630
2017	43	3	12,936	11,534
2018	43	3	14,093	12,721
2019	43	3	15,395	13,969
2020	43	3	16,585	14,974
2021	43	3	18,295	16,951
2022	43	3	19,546	18,078
2015	15	4	10,776	10,637
2016	15	4	11,609	11,463
2017	15	4	12,584	12,184

2018	15	4	13,803	12,661
2019	15	4	15,283	13,816
2020	15	4	16,567	13,594
2021	15	4	18,337	15,691
2022	15	4	19,641	15,444
2015	51	4	10,247	9,251
2016	51	4	11,203	10,192
2017	51	4	12,227	11,397
2018	51	4	13,331	12,723
2019	51	4	14,670	14,056
2020	51	4	15,929	14,953
2021	51	4	17,575	16,444
2022	51	4	18,672	17,199
2015	61	4	8,689	7,901
2016	61	4	9,396	8,568
2017	61	4	10,265	9,306
2018	61	4	11,213	10,071
2019	61	4	12,326	10,935
2020	61	4	13,316	11,376
2021	61	4	14,745	13,158
2022	61	4	15,704	14,094
2015	53	4	8,242	6,830
2016	53	4	9,020	7,331
2017	53	4	9,862	8,027
2018	53	4	10,768	9,123
2019	53	4	11,902	10,260
2020	53	4	12,842	11,069
2021	53	4	14,197	12,386
2022	53	4	15,147	13,309
2015	62	4	6,936	6,830
2016	62	4	7,457	7,487
2017	62	4	8,076	8,030
2018	62	4	8,804	9,065
2019	62	4	9,629	9,694
2020	62	4	10,344	9,923
2021	62	4	11,433	11,206
2022	62	4	12,165	11,494
2015	65	4	9,425	7,698
2016	65	4	10,183	8,277
2017	65	4	11,045	8,713
2018	65	4	11,975	9,421

2019	65	4	13,122	10,318
2020	65	4	14,056	10,778
2021	65	4	15,575	12,821
2022	65	4	16,550	12,169

Appendix 3 - 2015-2022 Control Variables in Various Provinces in China

year	Province code	Pro	Output of Grain Corps(1000tons)	Areas Affected by Natural Disaster(1000 hectares)	Total Power of Agricultural Machinery(10000 kw)
year	Province code	Pro	OOGC	ND	PM
2015	23	1	7,615.78	844.20	5,442.29
2016	23	1	7,416.13	2,663.70	5,634.27
2017	23	1	7,410.34	424.10	5,813.76
2018	23	1	7,506.80	1,450.60	6,084.65
2019	23	1	7,503.01	1,430.70	6,359.08
2020	23	1	7,540.78	701.70	6,775.09
2021	23	1	7,867.72	387.40	6,912.13
2022	23	1	7,763.14	32.40	7,090.88
2015	22	1	3,974.10	414.70	3,152.54
2016	22	1	4,150.70	456.80	3,105.27
2017	22	1	4,154.00	521.60	3,284.65
2018	22	1	3,632.74	344.90	3,466.00
2019	22	1	3,877.93	197.20	3,653.74
2020	22	1	3,803.17	591.20	3,896.95
2021	22	1	4,039.24	47.80	4,149.23
2022	22	1	4,080.79	76.70	4,357.86
2015	21	1	2,186.61	973.10	2,813.86
2016	21	1	2,315.60	122.70	2,168.45
2017	21	1	2,330.74	292.10	2,215.14
2018	21	1	2,192.45	465.30	2,243.72
2019	21	1	2,429.95	77.80	2,353.89
2020	21	1	2,338.83	905.50	2,471.26
2021	21	1	2,538.74	90.80	2,552.60
2022	21	1	2,484.54	332.60	2,657.84
2015	13	2	3,602.19	967.70	11,102.81
2016	13	2	3,782.99	561.80	7,401.97
2017	13	2	3,829.25	336.30	7,580.58
2018	13	2	3,700.86	356.00	7,706.20
2019	13	2	3,739.24	145.00	7,830.72
2020	13	2	3,795.89	94.70	7,965.74
2021	13	2	3,825.09	192.10	8,096.81
2022	13	2	3,865.06	58.50	8,249.08
2015	32	2	3,594.71	285.10	4,825.49
2016	32	2	3,542.44	66.60	4,906.55

2017	32	2	3,610.80	58.50	4,991.41
2018	32	2	3,660.28	177.40	5,017.71
2019	32	2	3,706.20	58.10	5,111.95
2020	32	2	3,729.06	46.80	5,213.83
2021	32	2	3,746.10	15.30	5,148.24
2022	32	2	3,769.13	43.20	5,264.08
2015	35	2	500.05	115.50	1,384.13
2016	35	2	477.28	193.70	1,269.09
2017	35	2	487.15	26.00	1,232.42
2018	35	2	498.58	48.40	1,228.27
2019	35	2	493.90	56.70	1,237.73
2020	35	2	502.32	21.10	1,260.20
2021	35	2	506.42	16.50	1,270.52
2022	35	2	508.70	22.50	1,296.71
2015	37	2	5,153.07	663.70	13,353.02
2016	37	2	5,332.28	228.30	9,797.61
2017	37	2	5,374.31	311.30	10,144.05
2018	37	2	5,319.51	574.50	10,415.22
2019	37	2	5,357.00	685.30	10,679.84
2020	37	2	5,446.81	88.80	10,964.66
2021	37	2	5,500.75	19.20	11,186.07
2022	37	2	5,543.78	13.30	11,530.49
2015	44	2	1,211.66	494.60	2,696.79
2016	44	2	1,204.22	187.60	2,390.50
2017	44	2	1,208.56	132.30	2,410.77
2018	44	2	1,193.49	169.20	2,429.94
2019	44	2	1,240.80	44.20	2,455.79
2020	44	2	1,267.56	26.50	2,495.43
2021	44	2	1,279.87	32.10	2,524.48
2022	44	2	1,291.54	50.70	2,556.30
2015	14	3	1,314.02	548.40	3,351.65
2016	14	3	1,380.33	206.80	1,744.26
2017	14	3	1,355.10	370.60	1,376.30
2018	14	3	1,380.40	587.00	1,441.09
2019	14	3	1,361.80	586.70	1,517.57
2020	14	3	1,424.27	284.70	1,595.26
2021	14	3	1,421.25	402.30	1,654.25
2022	14	3	1,464.25	84.00	1,714.27
2015	34	3	4,077.23	556.20	6,580.99
2016	34	3	3,961.76	557.60	6,867.50
2017	34	3	4,019.71	201.60	6,312.86

2018	34	3	4,007.25	468.40	6,543.81
2019	34	3	4,054.00	526.00	6,650.47
2020	34	3	4,019.22	779.90	6,799.50
2021	34	3	4,087.56	62.60	6,924.31
2022	34	3	4,100.13	71.30	7,070.12
2015	36	3	2,235.61	331.40	2,260.82
2016	36	3	2,234.40	393.60	2,201.62
2017	36	3	2,221.73	308.70	2,309.60
2018	36	3	2,190.70	363.40	2,381.97
2019	36	3	2,157.45	666.60	2,470.66
2020	36	3	2,163.88	324.30	2,591.05
2021	36	3	2,192.33	135.30	2,695.35
2022	36	3	2,151.91	525.10	2,838.16
2015	41	3	6,470.22	73.40	11,710.08
2016	41	3	6,498.01	238.40	9,854.96
2017	41	3	6,524.25	648.50	10,038.32
2018	41	3	6,648.91	850.50	10,204.46
2019	41	3	6,695.36	384.00	10,356.97
2020	41	3	6,825.80	145.50	10,463.70
2021	41	3	6,544.17	672.00	10,650.20
2022	41	3	6,789.37	67.00	10,858.66
2015	42	3	2,914.75	514.80	4,468.12
2016	42	3	2,796.35	1,505.60	4,187.75
2017	42	3	2,846.13	715.00	4,335.09
2018	42	3	2,839.47	475.90	4,424.61
2019	42	3	2,724.98	475.50	4,515.73
2020	42	3	2,727.43	782.30	4,626.07
2021	42	3	2,764.33	206.00	4,731.46
2022	42	3	2,741.15	338.90	4,878.65
2015	43	3	3,094.21	420.40	5,894.06
2016	43	3	3,052.30	582.20	6,097.54
2017	43	3	3,073.60	557.00	6,254.83
2018	43	3	3,022.90	309.90	6,338.57
2019	43	3	2,974.84	405.80	6,471.82
2020	43	3	3,015.12	221.40	6,588.95
2021	43	3	3,074.36	141.30	6,676.40
2022	43	3	3,018.02	344.70	6,755.95
2015	15	4	3,292.58	1,740.40	3,805.11
2016	15	4	3,263.28	2,277.50	3,331.09
2017	15	4	3,254.54	2,418.00	3,483.55
2018	15	4	3,553.28	1,580.30	3,663.66

2019	15	4	3,652.54	621.80	3,866.42
2020	15	4	3,664.10	1,258.80	4,056.58
2021	15	4	3,840.30	760.20	4,239.42
2022	15	4	3,900.63	885.30	4,596.42
2015	51	4	3,394.60	228.40	4,404.55
2016	51	4	3,469.93	242.10	4,267.32
2017	51	4	3,488.90	130.90	4,420.30
2018	51	4	3,493.70	295.10	4,603.88
2019	51	4	3,498.50	132.10	4,682.30
2020	51	4	3,527.43	230.50	4,754.00
2021	51	4	3,582.14	66.60	4,833.88
2022	51	4	3,510.55	208.50	4,923.33
2015	61	4	1,204.67	464.80	2,667.27
2016	61	4	1,263.96	364.60	2,171.91
2017	61	4	1,194.20	312.30	2,242.51
2018	61	4	1,226.00	276.10	2,311.79
2019	61	4	1,231.13	219.30	2,331.49
2020	61	4	1,274.83	258.20	2,387.96
2021	61	4	1,270.43	316.50	2,431.21
2022	61	4	1,297.89	177.30	2,473.88
2015	53	4	1,791.27	607.40	3,333.04
2016	53	4	1,815.07	437.30	3,440.64
2017	53	4	1,843.42	233.10	3,534.53
2018	53	4	1,860.54	172.20	2,693.51
2019	53	4	1,870.03	540.60	2,714.40
2020	53	4	1,895.86	420.30	2,786.75
2021	53	4	1,930.30	212.40	2,838.89
2022	53	4	1,957.96	372.20	2,913.65
2015	62	4	1,154.58	583.50	2,684.95
2016	62	4	1,117.48	814.90	1,903.90
2017	62	4	1,105.90	375.70	2,018.59
2018	62	4	1,151.43	527.10	2,102.80
2019	62	4	1,162.58	87.60	2,174.01
2020	62	4	1,202.21	142.00	2,289.53
2021	62	4	1,231.46	321.10	2,384.85
2022	62	4	1,264.99	125.20	2,516.66
2015	65	4	1,895.32	589.40	2,489.32
2016	65	4	1,552.33	506.40	2,552.15
2017	65	4	1,484.73	226.60	2,638.84
2018	65	4	1,504.23	501.90	2,731.79
2019	65	4	1,527.07	246.20	2,788.97

2020	65	4	1,583.40	350.90	2,929.44
2021	65	4	1,735.78	240.90	2,995.88
2022	65	4	1,813.50	56.40	3,075.35

Appendix 4- 2015-2021 Rural innovation and entrepreneurship index in Various Provinces in China

year	Province code	Pro	Rural innovation and entrepreneurship index
year	Province code	Pro	REI Index
2015	23	1	38.84
2016	23	1	41.01
2017	23	1	45.90
2018	23	1	47.35
2019	23	1	57.00
2020	23	1	63.71
2021	23	1	75.28
2015	22	1	46.35
2016	22	1	47.82
2017	22	1	48.12
2018	22	1	49.09
2019	22	1	45.10
2020	22	1	57.51
2021	22	1	62.86
2015	21	1	28.03
2016	21	1	37.00
2017	21	1	39.95
2018	21	1	43.50
2019	21	1	44.22
2020	21	1	50.05
2021	21	1	50.20
2015	13	2	41.24
2016	13	2	46.24
2017	13	2	51.79
2018	13	2	60.10
2019	13	2	63.61
2020	13	2	66.39
2021	13	2	63.41
2015	32	2	42.49
2016	32	2	43.12
2017	32	2	46.14
2018	32	2	48.38
2019	32	2	55.36

2020	32	2	58.66
2021	32	2	71.13
2015	35	2	60.61
2016	35	2	69.64
2017	35	2	77.56
2018	35	2	92.31
2019	35	2	99.25
2020	35	2	113.21
2021	35	2	138.95
2015	37	2	64.26
2016	37	2	67.70
2017	37	2	68.48
2018	37	2	71.73
2019	37	2	78.69
2020	37	2	84.34
2021	37	2	83.62
2015	44	2	28.93
2016	44	2	36.04
2017	44	2	53.65
2018	44	2	53.22
2019	44	2	58.56
2020	44	2	62.17
2021	44	2	61.05
2015	14	3	26.54
2016	14	3	27.83
2017	14	3	33.78
2018	14	3	33.34
2019	14	3	39.82
2020	14	3	54.09
2021	14	3	56.39
2015	34	3	46.97
2016	34	3	54.13
2017	34	3	58.78
2018	34	3	65.93
2019	34	3	66.63
2020	34	3	76.66
2021	34	3	78.57
2022	34	3	
2015	36	3	44.29
2016	36	3	51.88
2017	36	3	63.10

2018	36	3	64.56
2019	36	3	63.20
2020	36	3	67.44
2021	36	3	71.05
2015	41	3	33.55
2016	41	3	39.25
2017	41	3	42.45
2018	41	3	46.67
2019	41	3	50.20
2020	41	3	55.17
2021	41	3	55.98
2015	42	3	43.25
2016	42	3	43.31
2017	42	3	46.91
2018	42	3	54.35
2019	42	3	49.63
2020	42	3	50.93
2021	42	3	61.52
2015	43	3	33.42
2016	43	3	37.93
2017	43	3	46.17
2018	43	3	56.83
2019	43	3	55.10
2020	43	3	61.35
2021	43	3	59.04
2015	15	4	35.39
2016	15	4	38.19
2017	15	4	42.38
2018	15	4	53.44
2019	15	4	56.26
2020	15	4	62.55
2021	15	4	69.40
2015	51	4	42.30
2016	51	4	41.66
2017	51	4	45.14
2018	51	4	49.23
2019	51	4	55.46
2020	51	4	67.26
2021	51	4	72.55
2015	61	4	36.00
2016	61	4	39.27

2017	61	4	40.22
2018	61	4	49.75
2019	61	4	54.08
2020	61	4	67.28
2021	61	4	66.46
2015	53	4	43.61
2016	53	4	49.06
2017	53	4	51.36
2018	53	4	54.27
2019	53	4	55.09
2020	53	4	59.85
2021	53	4	63.06
2015	62	4	37.92
2016	62	4	38.77
2017	62	4	42.74
2018	62	4	52.60
2019	62	4	51.51
2020	62	4	60.99
2021	62	4	60.31
2015	65	4	45.31
2016	65	4	47.77
2017	65	4	49.85
2018	65	4	51.08
2019	65	4	52.00
2020	65	4	71.13
2021	65	4	71.28

Appendix 5- 2015-2021 Agricultural Carbon Emissions Calculation in Various Provinces in China

	Carbon emission factor	0.89	5.18	0.59	4.93	312.6	266.48							
province code	**year**	**Fertilizer Usage (10,000 tons)**	**Plastic Film Usage (tons)**	**Agricultural Diesel Usage (10,000 tons)**	**Pesticide Usage (tons)**	**Crop Planting Area (1,000 hectares)**	**Irrigation Area (1,000 hectares)**	**Carbon Emissions from Fertilizer (10,000 tons)**	**Carbon Emissions from Plastic Film (10,000 tons)**	**Carbon Emissions from Diesel (10,000 tons)**	**Carbon Emissions from Pesticides (10,000 tons)**	**Carbon Emissions from Tillage (10,000 tons)**	**Carbon Emissions from Irrigation (10,000 tons)**	**Agricultural Carbon Emissions (10,000 tons)**
23	2015	255.30	83,097.00	145.00	82,949.00	12,294.00	5,530.80	227.22	43.04	85.55	40.89	3.84	147.38	547.93
23	2016	252.80	82,575.00	145.50	82,474.00	14,829.50	5,932.70	224.99	42.77	85.85	40.66	4.64	158.09	557.00
23	2017	251.20	79,770.00	146.80	83,218.00	14,767.60	6,031.00	223.57	41.32	86.61	41.03	4.62	160.71	557.86
23	2018	245.60	77,431.00	147.40	74,182.00	14,673.30	6,119.60	218.58	40.11	86.97	36.57	4.59	163.08	549.89
23	2019	223.30	71,831.00	137.40	64,267.00	14,770.10	6,177.60	198.74	37.21	81.07	31.68	4.62	164.62	517.93
23	2020	224.20	70,501.00	138.50	60,749.00	14,910.10	6,171.60	199.54	36.52	81.72	29.95	4.66	164.46	516.84
23	2021	239.00	61,009.00	140.30	57,090.00	15,065.03	6,220.51	212.71	31.60	82.78	28.15	4.71	165.76	525.71
22	2015	231.20	59,164.00	66.70	62,285.00	5,679.10	1,790.90	205.77	30.65	39.35	30.71	1.78	47.72	355.97
22	2016	233.60	59,565.00	67.00	58,523.00	6,063.20	1,832.20	207.90	30.85	39.53	28.85	1.90	48.82	357.86
22	2017	231.00	60,752.00	67.60	56,294.00	6,086.20	1,893.10	205.59	31.47	39.88	27.75	1.90	50.45	357.05
22	2018	228.30	56,216.00	67.30	50,991.00	6,080.90	1,893.10	203.19	29.12	39.71	25.14	1.90	50.45	349.50
22	2019	227.10	53,130.00	65.70	48,658.00	6,117.10	1,909.50	202.12	27.52	38.76	23.99	1.91	50.88	345.19
22	2020	225.30	51,364.00	65.80	46,930.00	6,151.00	1,905.40	200.52	26.61	38.82	23.14	1.92	50.78	341.78
22	2021	223.00	47,651.00	64.80	45,139.00	6,187.06	1,918.95	198.47	24.68	38.23	22.25	1.93	51.14	336.71
21	2015	152.10	141,942.00	72.50	59,875.00	4,219.90	1,520.30	135.37	73.53	42.78	29.52	1.32	40.51	323.02
21	2016	148.10	137,273.00	70.70	56,264.00	4,242.70	1,573.00	131.81	71.11	41.71	27.74	1.33	41.92	315.61
21	2017	145.50	124,791.00	69.30	57,474.00	4,172.30	1,610.60	129.50	64.64	40.89	28.33	1.30	42.92	307.58
21	2018	145.00	117,976.00	62.40	55,070.00	4,207.10	1,619.30	129.05	61.11	36.82	27.15	1.32	43.15	298.59
21	2019	139.90	113,505.00	59.90	51,074.00	4,217.10	1,629.20	124.51	58.80	35.34	25.18	1.32	43.41	288.56
21	2020	137.60	114,381.00	59.20	44,722.00	4,287.80	1,632.50	122.46	59.25	34.93	22.05	1.34	43.50	283.53
21	2021	135.00	114,384.00	58.70	43,386.00	4,328.94	1,693.05	120.15	59.25	34.63	21.39	1.35	45.12	281.89
13	2015	335.50	137,983.00	293.20	83,328.00	8,739.80	4,448.00	298.60	71.48	172.99	41.08	2.73	118.53	705.40
13	2016	331.80	138,434.00	218.70	81,691.00	8,467.50	4,457.60	295.30	71.71	129.03	40.27	2.65	118.79	657.75
13	2017	322.00	128,100.00	224.60	77,623.00	8,381.60	4,474.70	286.58	66.36	132.51	38.27	2.62	119.24	645.58
13	2018	312.40	109,833.00	217.60	61,450.00	8,197.10	4,492.30	278.04	56.89	128.38	30.29	2.56	119.71	615.88
13	2019	297.30	103,211.00	200.10	57,344.00	8,132.70	4,482.20	264.60	53.46	118.06	28.27	2.54	119.44	586.37
13	2020	285.70	103,742.00	140.50	54,289.00	8,089.40	4,470.00	254.27	53.74	82.90	26.76	2.53	119.12	539.32
13	2021	276.90	102,039.00	134.50	52,691.00	8,097.20	3,952.24	246.44	52.86	79.36	25.98	2.53	105.32	512.48

	Carbon emission factor	0.89	5.18	0.59	4.93	312.6	266.48							
province code	year	Fertilizer Usage (10,000 tons)	Plastic Film Usage (tons)	Agricultural Diesel Usage (10,000 tons)	Pesticide Usage (tons)	Crop Planting Area (1,000 hectares)	Irrigation Area (1,000 hectares)	Carbon Emissions from Fertilizer (10,000 tons)	Carbon Emissions from Plastic Film (10,000 tons)	Carbon Emissions from Diesel (10,000 tons)	Carbon Emissions from Pesticides (10,000 tons)	Carbon Emissions from Tillage (10,000 tons)	Carbon Emissions from Irrigation (10,000 tons)	Agricultural Carbon Emissions (10,000 tons)
32	2015	320.00	113,243.00	108.60	78,100.00	7,745.00	3,952.50	284.80	58.66	64.07	38.50	2.42	105.33	553.78
32	2016	312.50	113,941.00	108.70	76,184.00	7,639.90	4,054.10	278.13	59.02	64.13	37.56	2.39	108.03	549.26
32	2017	303.90	115,085.00	109.00	73,167.00	7,556.40	4,131.90	270.47	59.61	64.31	36.07	2.36	110.11	542.94
32	2018	292.50	116,064.00	109.40	69,600.00	7,520.20	4,179.80	260.33	60.12	64.55	34.31	2.35	111.38	533.04
32	2019	286.20	114,153.00	108.90	67,396.00	7,442.60	4,205.40	254.72	59.13	64.25	33.23	2.33	112.07	525.72
32	2020	280.80	111,776.00	108.60	65,703.00	7,478.40	4,224.70	249.91	57.90	64.07	32.39	2.34	112.58	519.20
32	2021	275.60	105,775.00	104.30	63,547.00	7,514.45	3,826.29	245.28	54.79	61.54	31.33	2.35	101.96	497.25
35	2015	123.80	62,067.00	86.20	55,770.00	2,331.30	1,061.70	110.18	32.15	50.86	27.49	0.73	28.29	249.71
35	2016	123.80	62,424.00	86.30	55,387.00	1,548.80	1,055.40	110.18	32.34	50.92	27.31	0.48	28.12	249.35
35	2017	116.30	62,415.00	83.60	52,167.00	1,549.30	1,064.80	103.51	32.33	49.32	25.72	0.48	28.37	239.74
35	2018	110.70	60,002.00	82.40	49,143.00	1,577.30	1,085.20	98.52	31.08	48.62	24.23	0.49	28.92	231.86
35	2019	106.30	58,507.00	81.20	45,477.00	1,599.30	1,076.80	94.61	30.31	47.91	22.42	0.50	28.69	224.44
35	2020	100.80	51,824.00	78.40	43,163.00	1,631.30	1,110.40	89.71	26.84	46.26	21.28	0.51	29.59	214.19
35	2021	96.60	46,304.00	78.00	41,689.00	1,651.87	825.77	85.97	23.99	46.02	20.55	0.52	22.01	199.05
37	2015	463.50	301,575.00	165.80	151,004.00	11,026.50	4,964.40	412.52	156.22	97.82	74.44	3.45	132.29	876.74
37	2016	456.50	297,961.00	162.50	148,640.00	11,278.60	5,161.20	406.29	154.34	95.88	73.28	3.53	137.54	870.84
37	2017	440.00	287,098.00	157.70	140,670.00	11,107.80	5,191.10	391.60	148.72	93.04	69.35	3.47	138.33	844.51
37	2018	420.30	276,935.00	147.50	129,882.00	11,076.80	5,236.00	374.07	143.45	87.03	64.03	3.46	139.53	811.57
37	2019	395.30	267,113.00	137.60	120,342.00	10,933.10	5,271.40	351.82	138.36	81.18	59.33	3.42	140.47	774.58
37	2020	380.90	265,659.00	126.40	114,311.00	10,889.10	5,293.60	339.00	137.61	74.58	56.36	3.40	141.06	752.01
37	2021	371.00	259,678.00	122.20	108,230.00	10,948.59	5,069.92	330.19	134.51	72.10	53.36	3.42	135.10	728.68
44	2015	256.50	46,795.00	78.70	113,782.00	4,784.70	1,771.30	228.29	24.24	46.43	56.09	1.50	47.20	403.75
44	2016	261.00	45,505.00	79.90	113,652.00	4,181.60	1,771.70	232.29	23.57	47.14	56.03	1.31	47.21	407.55
44	2017	258.30	45,867.00	77.70	112,958.00	4,227.50	1,774.60	229.89	23.76	45.84	55.69	1.32	47.29	403.79
44	2018	231.30	44,814.00	88.50	93,684.00	4,279.40	1,775.20	205.86	23.21	52.22	46.19	1.34	47.31	376.12
44	2019	225.80	43,842.00	85.50	87,489.00	4,357.40	1,773.40	200.96	22.71	50.45	43.13	1.36	47.26	365.87
44	2020	219.80	42,558.00	85.80	83,217.00	4,451.80	1,776.50	195.62	22.05	50.62	41.03	1.39	47.34	358.05
44	2021	212.90	43,027.00	85.40	77,440.00	4,498.36	1,529.21	189.48	22.29	50.39	38.18	1.41	40.75	342.49

	Carbon emission factor	0.89	5.18	0.59	4.93	312.6	266.48							
province code	year	Fertilizer Usage (10,000 tons)	Plastic Film Usage (tons)	Agricultural Diesel Usage (10,000 tons)	Pesticide Usage (tons)	Crop Planting Area (1,000 hectares)	Irrigation Area (1,000 hectares)	Carbon Emissions from Fertilizer (10,000 tons)	Carbon Emissions from Plastic Film (10,000 tons)	Carbon Emissions from Diesel (10,000 tons)	Carbon Emissions from Pesticides (10,000 tons)	Carbon Emissions from Tillage (10,000 tons)	Carbon Emissions from Irrigation (10,000 tons)	Agricultural Carbon Emissions (10,000 tons)
14	2015	118.50	47,864.00	29.80	31,035.00	3,767.70	1,460.30	105.47	24.79	17.58	15.30	1.18	38.91	203.23
14	2016	117.10	48,922.00	29.20	30,550.00	3,591.50	1,487.30	104.22	25.34	17.23	15.06	1.12	39.63	202.61
14	2017	112.00	49,998.00	28.50	28,831.00	3,577.60	1,511.20	99.68	25.90	16.82	14.21	1.12	40.27	198.00
14	2018	109.60	49,067.00	27.60	26,543.00	3,555.20	1,518.70	97.54	25.42	16.28	13.09	1.11	40.47	193.91
14	2019	108.40	48,555.00	26.40	25,319.00	3,524.40	1,519.30	96.48	25.15	15.58	12.48	1.10	40.49	191.27
14	2020	107.40	48,592.00	26.00	24,866.00	3,541.50	1,517.40	95.59	25.17	15.34	12.26	1.11	40.44	189.90
14	2021	105.60	47,890.00	25.80	23,594.00	3,587.95	1,498.06	93.98	24.81	15.22	11.63	1.12	39.92	186.69
34	2015	338.70	97,943.00	75.70	111,048.00	8,950.50	4,400.30	301.44	50.73	44.66	54.75	2.80	117.26	571.64
34	2016	327.00	96,966.00	75.70	105,704.00	8,790.10	4,437.50	291.03	50.23	44.66	52.11	2.75	118.25	559.03
34	2017	318.70	97,601.00	75.50	99,394.00	8,726.70	4,504.10	283.64	50.56	44.55	49.00	2.73	120.03	550.50
34	2018	311.80	97,828.00	75.50	94,177.00	8,771.10	4,538.30	277.50	50.67	44.55	46.43	2.74	120.94	542.83
34	2019	298.00	103,735.00	74.70	88,271.00	8,782.00	4,580.80	265.22	53.73	44.07	43.52	2.75	122.07	531.36
34	2020	289.90	103,299.00	75.20	83,294.00	8,818.00	4,608.80	258.01	53.51	44.37	41.06	2.76	122.82	522.52
34	2021	284.70	102,605.00	74.40	75,993.00	8,886.77	4,509.87	253.38	53.15	43.90	37.46	2.78	120.18	510.85
36	2015	143.60	53,977.00	28.80	93,873.00	5,579.10	2,027.70	127.80	27.96	16.99	46.28	1.74	54.03	274.81
36	2016	142.00	52,757.00	27.80	92,188.00	5,668.90	2,036.80	126.38	27.33	16.40	45.45	1.77	54.28	271.61
36	2017	135.00	53,509.00	29.60	87,737.00	5,638.50	2,039.40	120.15	27.72	17.46	43.25	1.76	54.35	264.69
36	2018	123.20	52,218.00	30.90	77,183.00	5,555.80	2,032.00	109.65	27.05	18.23	38.05	1.74	54.15	248.86
36	2019	115.60	52,020.00	30.10	62,701.00	5,521.20	2,036.10	102.88	26.95	17.76	30.91	1.73	54.26	234.48
36	2020	108.80	52,296.00	30.00	52,708.00	5,644.40	2,038.50	96.83	27.09	17.70	25.99	1.76	54.32	223.69
36	2021	108.60	52,196.00	29.90	51,629.00	5,672.94	2,158.03	96.65	27.04	17.64	25.45	1.77	57.51	226.07
41	2015	716.10	162,001.00	114.70	128,748.00	14,425.00	5,210.60	637.33	83.92	67.67	63.47	4.51	138.85	995.75
41	2016	715.00	163,149.00	112.40	127,107.00	14,902.70	5,242.90	636.35	84.51	66.32	62.66	4.66	139.71	994.21
41	2017	706.70	157,298.00	108.80	120,713.00	14,732.50	5,273.60	628.96	81.48	64.19	59.51	4.61	140.53	979.28
41	2018	692.80	152,838.00	103.90	113,603.00	14,783.40	5,288.70	616.59	79.17	61.30	56.01	4.62	140.93	958.62
41	2019	666.70	150,762.00	100.10	107,231.00	14,714.00	5,328.90	593.36	78.09	59.06	52.86	4.60	142.00	929.99
41	2020	648.00	151,717.00	97.40	102,400.00	14,688.00	5,463.10	576.72	78.59	57.47	50.48	4.59	145.58	913.43
41	2021	624.70	140,352.00	95.30	97,432.00	14,705.13	5,518.24	555.98	72.70	56.23	48.03	4.60	147.05	884.59

	Carbon emission factor	0.89	5.18	0.59	4.93	312.6	266.48							
province code	year	Fertilizer Usage (10,000 tons)	Plastic Film Usage (tons)	Agricultural Diesel Usage (10,000 tons)	Pesticide Usage (tons)	Crop Planting Area (1,000 hectares)	Irrigation Area (1,000 hectares)	Carbon Emissions from Fertilizer (10,000 tons)	Carbon Emissions from Plastic Film (10,000 tons)	Carbon Emissions from Diesel (10,000 tons)	Carbon Emissions from Pesticides (10,000 tons)	Carbon Emissions from Tillage (10,000 tons)	Carbon Emissions from Irrigation (10,000 tons)	Agricultural Carbon Emissions (10,000 tons)
42	2015	333.90	71,321.00	65.60	120,685.00	7,952.40	2,899.10	297.17	36.94	38.70	59.50	2.49	77.26	512.06
42	2016	328.00	67,306.00	65.90	117,401.00	7,908.50	2,905.60	291.92	34.86	38.88	57.88	2.47	77.43	503.44
42	2017	317.90	65,876.00	66.30	109,588.00	7,956.10	2,919.20	282.93	34.12	39.12	54.03	2.49	77.79	490.48
42	2018	295.80	63,554.00	65.10	103,317.00	7,952.90	2,931.90	263.26	32.92	38.41	50.94	2.49	78.13	466.14
42	2019	273.90	58,801.00	63.50	97,024.00	7,815.90	2,969.00	243.77	30.46	37.47	47.83	2.44	79.12	441.09
42	2020	267.30	58,039.00	62.80	93,143.00	7,974.40	3,086.00	237.90	30.06	37.05	45.92	2.49	82.24	435.66
42	2021	262.60	57,268.00	62.40	90,468.00	8,109.24	3,111.09	233.71	29.66	36.82	44.60	2.53	82.90	430.23
43	2015	246.50	83,989.00	43.60	122,353.00	8,717.00	3,113.30	219.39	43.51	25.72	60.32	2.72	82.96	434.62
43	2016	246.40	84,679.00	43.70	118,661.00	8,341.50	3,132.40	219.30	43.86	25.78	58.50	2.61	83.47	433.52
43	2017	245.30	85,209.00	44.20	116,023.00	8,322.00	3,145.90	218.32	44.14	26.08	57.20	2.60	83.83	432.17
43	2018	242.60	85,397.00	44.60	114,155.00	8,111.10	3,164.00	215.91	44.24	26.31	56.28	2.54	84.31	429.59
43	2019	229.00	83,792.00	44.80	105,548.00	8,122.80	3,176.10	203.81	43.40	26.43	52.04	2.54	84.64	412.86
43	2020	223.70	83,005.00	45.20	101,450.00	8,400.10	3,192.90	199.09	43.00	26.67	50.01	2.63	85.08	406.48
43	2021	219.10	79,094.00	46.00	91,114.00	8,504.26	2,875.06	195.00	40.97	27.14	44.92	2.66	76.61	387.30
15	2015	229.40	95,021.00	80.40	32,961.00	7,567.90	3,086.90	204.17	49.22	47.44	16.25	2.37	82.26	401.70
15	2016	234.60	95,631.00	81.00	32,339.00	8,957.20	3,131.50	208.79	49.54	47.79	15.94	2.80	83.45	408.31
15	2017	235.00	94,306.00	73.60	35,618.00	9,014.20	3,174.80	209.15	48.85	43.42	17.56	2.82	84.60	406.40
15	2018	222.70	93,969.00	79.20	29,585.00	8,824.10	3,196.50	198.20	48.68	46.73	14.59	2.76	85.18	396.13
15	2019	218.40	94,194.00	77.40	27,278.00	8,885.00	3,199.20	194.38	48.79	45.67	13.45	2.78	85.25	390.31
15	2020	207.70	95,297.00	78.10	23,426.00	8,882.80	3,199.10	184.85	49.36	46.08	11.55	2.78	85.25	379.87
15	2021	241.90	100,260.00	80.70	26,692.00	8,743.34	4,379.28	215.29	51.93	47.61	13.16	2.73	116.70	447.43
51	2015	249.80	132,170.00	46.90	58,912.00	9,689.90	2,735.10	222.32	68.46	27.67	29.04	3.03	72.88	423.41
51	2016	249.00	132,384.00	46.90	58,038.00	9,493.80	2,813.60	221.61	68.57	27.67	28.61	2.97	74.98	424.41
51	2017	242.00	130,993.00	46.70	55,751.00	9,575.10	2,873.10	215.38	67.85	27.55	27.49	2.99	76.56	417.83
51	2018	235.20	120,186.00	46.90	51,276.00	9,615.30	2,932.50	209.33	62.26	27.67	25.28	3.01	78.15	405.69
51	2019	222.80	123,235.00	47.00	46,290.00	9,693.00	2,954.10	198.29	63.84	27.73	22.82	3.03	78.72	394.43
51	2020	210.80	118,818.00	47.10	42,130.00	9,849.90	2,992.20	187.61	61.55	27.79	20.77	3.08	79.74	380.53
51	2021	207.20	116,968.00	47.00	40,974.00	9,999.92	2,784.14	184.41	60.59	27.73	20.20	3.13	74.19	370.25

	Carbon emission factor	0.89	5.18	0.59	4.93	312.6	266.48							
province code	year	Fertilizer Usage (10,000 tons)	Plastic Film Usage (tons)	Agricultural Diesel Usage (10,000 tons)	Pesticide Usage (tons)	Crop Planting Area (1,000 hectares)	Irrigation Area (1,000 hectares)	Carbon Emissions from Fertilizer (10,000 tons)	Carbon Emissions from Plastic Film (10,000 tons)	Carbon Emissions from Diesel (10,000 tons)	Carbon Emissions from Pesticides (10,000 tons)	Carbon Emissions from Tillage (10,000 tons)	Carbon Emissions from Irrigation (10,000 tons)	Agricultural Carbon Emissions (10,000 tons)
61	2015	231.90	43,068.00	92.30	13,092.00	4,284.50	1,236.80	206.39	22.31	54.46	6.45	1.34	32.96	323.91
61	2016	233.10	43,717.00	92.80	13,190.00	4,160.20	1,251.40	207.46	22.65	54.75	6.50	1.30	33.35	326.01
61	2017	232.10	43,954.00	93.40	13,335.00	4,063.90	1,263.10	206.57	22.77	55.11	6.57	1.27	33.66	325.95
61	2018	229.60	44,147.00	92.60	12,550.00	4,091.00	1,275.00	204.34	22.87	54.63	6.19	1.28	33.98	323.29
61	2019	202.50	44,780.00	93.80	12,240.00	4,132.10	1,285.20	180.23	23.20	55.34	6.03	1.29	34.25	300.34
61	2020	201.90	44,724.00	93.40	11,951.00	4,160.80	1,336.80	179.69	23.17	55.11	5.89	1.30	35.62	300.78
61	2021	200.70	44,294.00	91.90	11,643.00	4,189.27	1,192.47	178.62	22.94	54.22	5.74	1.31	31.78	294.61
53	2015	231.90	113,104.00	86.30	58,648.00	7,185.60	1,757.70	206.39	58.59	50.92	28.91	2.25	46.84	393.89
53	2016	235.60	115,926.00	84.80	58,601.00	6,786.60	1,809.40	209.68	60.05	50.03	28.89	2.12	48.22	398.99
53	2017	231.90	120,150.00	85.90	57,675.00	6,790.80	1,851.40	206.39	62.24	50.68	28.43	2.12	49.34	399.20
53	2018	217.40	119,685.00	25.40	52,591.00	6,890.80	1,898.10	193.49	62.00	14.99	25.93	2.15	50.58	349.13
53	2019	204.00	122,139.00	26.20	47,441.00	6,938.90	1,922.50	181.56	63.27	15.46	23.39	2.17	51.23	337.07
53	2020	196.70	121,558.00	30.40	44,846.00	6,989.70	1,978.10	175.06	62.97	17.94	22.11	2.18	52.71	332.97
53	2021	187.30	117,326.00	28.30	41,104.00	7,057.24	1,988.24	166.70	60.77	16.70	20.26	2.21	52.98	319.62
62	2015	97.90	183,735.00	42.70	78,848.00	4,229.30	1,306.70	87.13	95.17	25.19	38.87	1.32	34.82	282.51
62	2016	93.40	195,092.00	44.20	69,915.00	3,749.20	1,317.50	83.13	101.06	26.08	34.47	1.17	35.11	281.01
62	2017	84.50	172,188.00	45.50	51,995.00	3,752.00	1,331.40	75.21	89.19	26.85	25.63	1.17	35.48	253.53
62	2018	83.20	161,272.00	40.80	42,864.00	3,773.60	1,337.50	74.05	83.54	24.07	21.13	1.18	35.64	239.61
62	2019	80.90	152,253.00	39.10	41,938.00	3,831.60	1,328.90	72.00	78.87	23.07	20.68	1.20	35.41	231.22
62	2020	80.40	152,956.00	36.10	40,312.00	3,931.80	1,338.60	71.56	79.23	21.30	19.87	1.23	35.67	228.86
62	2021	77.10	170,728.00	36.00	28,107.00	3,997.94	1,298.94	68.62	88.44	21.24	13.86	1.25	34.61	228.02
65	2015	248.10	268,901.00	86.30	25,838.00	5,757.30	4,944.90	220.81	139.29	50.92	12.74	1.80	131.77	557.33
65	2016	250.20	266,198.00	87.80	27,596.00	5,921.30	4,982.00	222.68	137.89	51.80	13.60	1.85	132.76	560.59
65	2017	250.70	252,646.00	88.30	27,670.00	5,887.00	4,952.30	223.12	130.87	52.10	13.64	1.84	131.97	553.54
65	2018	255.00	269,839.00	95.50	23,732.00	6,068.90	4,883.50	226.95	139.78	56.35	11.70	1.90	130.14	566.80
65	2019	257.80	262,677.00	94.20	22,948.00	6,170.00	4,959.90	229.44	136.07	55.58	11.31	1.93	132.17	566.50
65	2020	248.20	259,674.00	85.20	21,823.00	6,280.00	4,893.40	220.90	134.51	50.27	10.76	1.96	130.40	548.80
65	2021	240.70	261,479.00	85.80	20,388.00	6,387.42	6,666.39	214.22	135.45	50.62	10.05	2.00	177.65	589.99