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Exploration and countermeasures for the development of low-carbon agriculture: a study from Chongming District, Shanghai

Xuemei Song[1] and Yibo Dou[2*]

[1]Business School, University of Shanghai for Science and Technology, Shanghai, China, [2]School of Software, Xinjiang University, Urumqi, China

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EDITED BY
Xiaohang Ren,
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Bei Liu,
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Ya Tan,
University of International Business and Economics, China

*CORRESPONDENCE
Yibo Dou
dyb666@stu.xju.edu.cn

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To achieve the goals of carbon peaking and carbon neutrality, China is actively promoting carbon reduction in many areas. Agriculture is one of the main sources of greenhouse gas emissions, and promoting the development of low-carbon agriculture is a critical way to achieve carbon reduction targets. Taking Chongming District in Shanghai as an example, this study summarizes the experience of low-carbon agricultural development in Chongming and analyzes the problems and challenges faced during its development. Finally, based on the system dynamics method, the causal relationship of carbon emission in Chongming's agricultural development is constructed, and feasible loop optimization suggestions are put forward.

KEYWORDS

low-carbon agriculture, carbon emissions, system dynamics, climate change, causal loop diagram

1 Introduction

Global climate change, as a common issue facing all countries worldwide, seriously threatens the sustainable development of human society (Streimikiene et al., 2012). In 2015, the Paris Agreement set a long-term temperature goal, and to achieve it, many countries made new carbon-neutral or zero-emission commitments, such as the European Union, Japan, the Republic of Korea, Canada, and others (European Commission, 2018; Canada Government, 2020; NPR, 2020; Tradelink Publications, 2020). As an activist and advocate of global climate governance, China has always aimed to promote global sustainable development and build a community with a shared future for mankind (Yang et al., 2010). On September 22, 2020, Chinese President Xi Jinping announced at the 75th session of the United Nations General Assembly that China is striving to reach peak CO2 emissions by 2030 and achieve carbon neutrality by 2060. The Chinese Government has taken the initiative to increase the country's autonomous contribution by adopting more vigorous policies and measures in an integrated manner in both the international and domestic contexts (Shi and He, 2023).

Agriculture is the basis of the national economy and is also a critical carbon source and sink sector. On the one hand, agriculture is one of the main sources of greenhouse gas emissions, and processes such as fertilizer application, pesticide use, and livestock and poultry breeding in agricultural production generate large amounts of greenhouse gases (Nayak et al., 2015; Crippa et al., 2021). On the other hand, as a carbon sink sector, agro-ecosystems have a massive potential for carbon reduction (Chen et al., 2013). The core of low-carbon agriculture is to promote the green transformation of the agricultural development mode, and low-carbon agricultural practices are an essential way to realize carbon emission reduction and cope with the climate crisis (Bai et al., 2019).

Low-carbon agriculture-related initiatives have been introduced in many countries and regions (Xie et al., 2022). USDA releases plans and studies such as the U.S. Agricultural Innovation Strategy and the Climate-Smart Agriculture and Forestry Strategy: 90-Day Progress Report to create climate-smart agriculture through technological innovation (United States Department of Agriculture 2021a; 2021b). The European Commission has published strategies such as the Farm to Fork Strategy, which advocates nature-based solutions to achieve development goals (European Commission, 2021). In 2021, the Chinese government issued the “14th Five-Year National Agricultural Green Development Plan”, which proposed the creation of a green and low-carbon agricultural industry chain. For the first time, the goal of emission reduction and carbon sequestration was incorporated into the agricultural development plan (MARA, 2021). “Action Plan for Carbon Dioxide Peaking Before 2030”, which has since been released, explicitly promotes emission reductions and carbon sequestration in agriculture and rural areas (The State Council of the People's Republic of China, 2021). “Agricultural and rural carbon emission reduction and sequestration implementation plan” proposes implementing ten significant actions to promote the development of low-carbon agriculture (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022a). Policy-level efforts open up new horizons for low-carbon agricultural development (Ren et al., 2023).

In this study, the Chongming District of Shanghai was chosen as a typical case to study low-carbon agriculture. First, the “Outline of the Development Plan for Chongming World-Class Eco-Island (2021-2035)” issued by the Shanghai Municipal People’s Government proposes to build Chongming Island into a world-class eco-island (Shanghai Municipal People’s Government, 2022). Urban modern green agriculture is one of the essential ecological industries in Chongming (Yang et al., 2022). In creating carbon-neutral demonstration zones, promoting low-carbon agriculture development is particularly important (Luo et al., 2011). Second, the Chinese government has taken Chongming District as a typical case of national agricultural green development, which provides a valuable reference for the development of low-carbon agriculture in other regions (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022e).

Therefore, the contribution of this study is as follows. This paper uses case studies that can provide a more comprehensive account of the efforts made by Chongming District in the development of low-carbon agriculture for reference. Secondly, the system dynamics approach was not used by Luo et al. (2011) and Li and Wang (2023), but the approach can reveal the causal relationship of carbon emissions from agricultural development. This study introduces a system dynamics approach to analyze agricultural carbon emissions in Chongming District and suggests loop optimization recommendations, which helps to consider what measures the government can take to guide low-carbon agricultural development in the context of climate change.

2 Exploration of low-carbon agricultural development in chongming

2.1 Development experience

Located at the mouth of the Yangtze River, the Chongming District of Shanghai consists of three islands, Chongming Island, Changxing Island and Hengsha Island, which are the largest estuarine alluvial islands in the world. As a world-class eco-island, the concept of green development should be followed in Chongming’s development (Ni et al., 2012; Cai et al., 2020). In the process of continuously adjusting the industrial structure, Chongming’s greenhouse gas emissions peaked in 2008 and have shown a steady decline. Economic growth has been decoupled from energy consumption and carbon emissions (Chongming District Government, 2022a). Ecological low-carbon agriculture occupies an important position in Chongming’s industrial structure. After 20 years of eco-island construction, Chongming has formed a series of distinctive working experiences in developing low-carbon agriculture, including the model of circular agriculture, the model of new clean energy development, and the model of factory development.

The circular agriculture model aims to promote accurate monitoring and effective traceability of agricultural carbon emissions through the efficient and intensive utilization of various resources (Gao et al., 2007). Typical practical examples of circular agriculture models in Chongming mainly include the paddy field three-dimensional polyculture model and the ecological crab aquaculture model. The three-dimensional polyculture mode of paddy fields establishes a cyclic symbiosis mode by optimizing the structure of paddy fields, including the symbiosis of rice with shrimp, turtle, fish, and eel (Lu and Li, 2006; Guo et al., 2017). The model utilizes biological manipulation of the food chain and recycling techniques to form symbiotic complex systems (Zhang et al., 2023). At the same time, it also applies composite microbial agents to regulate water quality and improve soil, significantly reducing the use of chemical pesticides and fertilizers and effectively avoiding rice disease and pests (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022b). The ecological crab aquaculture model transforms the original aquaculture crab ponds and realizes the transformation and upgrading of traditional production capacity with the help of modern agricultural engineering design. This eco-efficient pond culture model recycles wastewater through the deployment of recirculating waterways, ecological interception barriers, water quality monitoring equipment, and the planting of water plants (Chongming District Government, 2023b).

To promote a low-carbon transition in agriculture, Chongming promotes the sustainable development of the agricultural industry and the way energy is utilized through clean energy (Chongming District Government, 2022c). Located in Chenjia Township, the fish breeding and cultivation base covers an area of about 3,390 acres, with a total of 134 standardized fish ponds and a total installed capacity of 110 megawatts, which is a super-large-scale fishery-solar hybrid project. The project's average power generation for a year is about 118 million kWh, saving about 36,700 tons of coal for a year and reducing carbon dioxide emissions by about 99,000 tons, sulfur dioxide by about 30.7 tons, nitrogen oxides by about 29.5 tons, and carbon dust by about 7.1 tons for a year (Chongming District Government, 2022d). These projects have optimized the energy structure of the region and promoted energy conservation and emission reduction (Guo and Yang, 2012; Wei et al., 2021; Peng et al., 2023).

Since 2018, Chongming has made full use of its market advantage of being backed by an international metropolis and combined with its ecological background to attract several modern agricultural factories integrating research and production. This agricultural factory realizes efficient and intensive use of resources and can effectively reduce carbon emissions (Burney et al., 2010). The Youyou Agricultural Innovation Park has constructed a substantial semi-closed glass greenhouse of 206,600 square meters, where vegetable growing and a central control system controls nursery areas, and the temperature and humidity in the greenhouse can be precisely adjusted (Chongming District Government, 2022b). In addition, the greenhouse filters rainwater through a rainwater cistern for precise irrigation, and the wastewater, after watering, is reused through recycling. Chongming's development model enables science and technology innovation to further boost green and low-carbon agriculture.

2.2 Problems and challenges

Although Chongming has adopted various forms of agricultural emissions reduction, the low-carbon development of agriculture still faces many challenges due to its characteristics and current economic development.

(1)Agricultural carbon emissions are inevitable.

Agriculture is an important source of greenhouse gas emissions (Cheng et al., 2011; Tian et al., 2014). According to statistics, carbon emissions from agricultural sources in Chongming District account for about 20% of the district's greenhouse gas emissions. Analyzed by emission type, greenhouse gas emissions from agricultural sources are mainly methane emissions from rice paddies and nitrous oxide from agricultural land, accounting for 70% of the total emissions from agricultural sources. Chongming's rice planting area is 17,976 hectares, accounting for 1/5 of Shanghai's rice planting area Chongming Statistical Yearbook (2022). During rice cultivation, methane emissions come from two main sources: One is the physiological metabolic process of the rice plant, and the other is the decomposition of organic matter in the paddy soil by anaerobic microorganisms (Fu et al., 2006; Asakawa, 2021). If the straw is directly returned to the field for utilization, the rice straw in the soil can easily decompose under an anaerobic environment to produce methane gas emissions (Conrad and Rothfuss, 1991). Nitrous oxide emissions from agricultural land are also not to be ignored. (Firestone and Davidson, 1989; Haider et al., 2021). Ranking third and fourth in carbon emissions from agricultural sources in Chongming are methane and nitrous oxide emissions from animal manure and methane from animal enteric fermentation, accounting for 15%-20% and 7%-9% of the total emissions from agricultural sources, respectively (Hamilton et al., 2010; Rotz, 2018). In addition, the production of agricultural machinery may also generate carbon dioxide and methane (Zhou, 2020).

(2)The foundations for low-carbon development in agriculture are still relatively weak.

In recent years, many research results related to low-carbon agriculture have been tested in Chongming (Mekhilef et al., 2013; Jiang et al., 2022; Li et al., 2022). From the perspective of emission reduction technology application, measures such as straw reuse, fertilizer and pesticide reduction, and application of organic fertilizers reduced methane and nitrous oxide emissions during rice cultivation (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022d). However, the increased input of soil organic matter from rice straw returning to the field also produces more intensive methane gas emissions, so the optimal ratio of straw returning to the field and the way to utilize it need further research (Zhang et al., 2021). Currently, Chongming is actively promoting the construction of the National Observatory for Green Development of Agriculture (Chongming District Government, 2023a). However, monitoring and applying results to decentralized agricultural business entities is difficult. In terms of abatement input costs and outputs, low-carbon agricultural technologies have higher input costs compared to previous agricultural production (Wang and Zhang, 2022). It is still difficult to promote the application of low-carbon agricultural technologies in an innovative way for ordinary farmers, who are increasingly aging and more conservative in their thinking, and they need policy guidance and support from government departments. Market acceptance of low-carbon agricultural products is also based on the concept of green and organic agricultural products, which is strongly influenced by the price factor (Zhang et al., 2019).

3 System dynamics causality construction

3.1 System dynamics modeling

To further promote the development of low-carbon agriculture in Chongming, it is necessary to model the causal relationship of agricultural carbon emissions in Chongming as a basis for analysis and recommendations.

System dynamics focuses on the interrelationships between internal and external factors of a system to provide effective guidance for decision-making (Sterman, 2001). Causal diagrams are the main analytical tool in system dynamics and have been applied in many data-rich ecosystems (Forrester, 1961; Meadows et al., 1972; Homer and Hirsch, 2006; Elsawah et al., 2017; Lin et al., 2020). Agricultural carbon emissions involve many aspects of agricultural production, and the main variable factors are production scale, energy use, policies, financial inputs, the level of application of scientific and technological achievements, and the popularization of the concept of emission reduction. Based on the system dynamics analysis, the causal loop diagram obtained is shown in Figure 1.

After analysis, the causality of Chongming's low-carbon agricultural development is constructed to form 46 loops, which directly or indirectly contribute to agricultural carbon emissions.

(1) Reverse Carbon Reduction Loops: Seven main loops are listed.

Loop 1: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Fiscal Input → Talent, Science and Technology Policy Support → Talent Capital Input, R&D Capital Input → Scientific and Technological Achievements → Application of fertilizer efficiency enhancement technology → Fertilizer Usage → Carbon Emission from Rice Cultivation → Agrochemical Carbon Emissions → Agricultural Carbon Emission.

Loop 2: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Fiscal Input → Talent, Science and Technology Policy Support → Talent Capital Input, R&D Capital Input → Scientific and Technological Achievements → Application and Popularization of Green Breeding Techniques → Livestock and Poultry Manure and Enteral Fermentation → Livestock and Poultry Carbon Emissions → Agricultural Carbon Emissions.

Loop 3: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Financial Inputs → R&D Capital Input → Scientific and Technological Achievements → Utilization of New Agricultural Energy → Total Fossil Energy Use of Agricultural Machines → Agricultural Machinery Carbon Emissions → Agricultural Carbon Emissions.

Loop 4: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Fiscal Input → Fixed Asset Investment in Low-Carbon Agriculture → Application of Emission Reduction Technologies → Agricultural Carbon Emissions.

Loop 5: Agricultural Carbon Emissions → Policy Objectives → Energy Saving and Emission Reduction Publicity Efforts → Farmers' Awareness of Energy Saving and Emission Reduction → Fertilizer and Pesticide Usage → Rice Cultivation Carbon Emissions → Agrochemical Carbon Emissions → Agricultural Carbon Emissions.

Loop 6: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Total Scale of Primary Industry → Rice Cultivation Area → Organic Fertilizer Usage → Rice Carbon Sequestration → Agricultural Carbon Emissions.

Loop 7: Agricultural Carbon Emissions → Policy Objectives → Ecological Treatment of Straw → Rice Straw → Rice Carbon Sequestration → Agricultural Carbon Emissions.

(2) Positive Carbon Increase Loops: Three main loops are listed.

Loop 8: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Total Scale of Primary Industry → Rice Cultivation Area → Fertilizer and

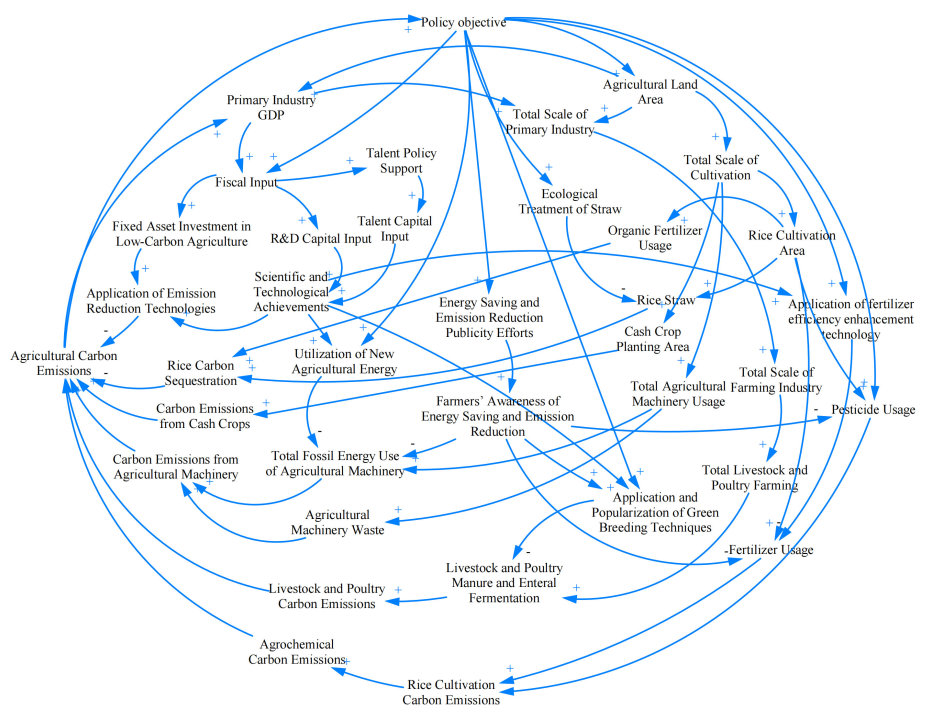

FIGURE 1
Causal loop diagram of low-carbon agricultural development.

Pesticide Usage → Rice Cultivation Carbon Emissions → Agrochemical Carbon Emissions → Agricultural Carbon Emissions.

Loop 9: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Primary Industry GDP → Total Scale of Primary Industry → Total Scale of Farming Industry → Total Livestock and Poultry Farming → Livestock and Poultry Manure and Enteral Fermentation → Livestock and Poultry Carbon Emissions → Agricultural Carbon Emissions.

Loop 10: Agricultural Carbon Emissions → Policy Objectives → Agricultural Land Area → Total Scale of Cultivation → Total Agricultural Machinery Usage → Agricultural Machinery Waste → Agricultural Machinery Carbon Emissions → Agricultural Carbon Emissions.

3.2 Loop optimization recommendations

By analyzing the main feedback loops obtained from the system dynamics approach described above, and taking into account the current development basis of agriculture in the region, the following loop optimization proposals were made.

The reverse carbon reduction loops 1-4 suggest that increased financial investment in low-carbon agriculture by government departments and more attractive talent policies will lead to a sustained focus on low-carbon agriculture by all sectors of society, including scientific research institutions and business organizations (Chen et al., 2020). In continuous exploration and practice, the fixed investment in low-carbon agriculture is increasing, and the achievements of agricultural science and technology will continue to emerge. Many new technologies and equipment have been put to the test and are being applied in areas such as fertilizer efficiency, green farming and new energy use, all of which will contribute to a high level of agricultural emissions reduction. Therefore, local government departments should formulate policy measures related to low-carbon agriculture and increase investment in fixed assets on the premise of actively seeking support. In addition, government departments should support the excellent scientific research team stationed in Chongming, and jointly carry out suitable for the development of low-carbon agriculture in Chongming project cooperation and research, which will be conducive to technological breakthroughs (Chen et al., 2021; Xue et al., 2021). The experience of the United States Agricultural Innovation Strategy could also be used as a basis for proposing corresponding innovation goals for normative data management and systematic management of agriculture (United States Department of Agriculture 2021b).

The reverse carbon reduction loop 5 suggests that strengthening the publicity work on the carbon peak and carbon neutral targets and the concept of green development in Chongming can effectively raise awareness of energy saving and emission reduction among farmers. Reductions in fertilizer and pesticide use have a direct impact on carbon emissions from agrochemicals, therefore reducing the total amount of carbon emissions from agriculture. Low-carbon agriculture, as a new model of agricultural development, needs to be promoted throughout society, especially by participants in the entire agricultural chain. Increased recognition of low-carbon agriculture by producers, operators, and consumers will contribute to better-promoting carbon emission reduction in agriculture. Japan's policy recommendations can be used for reference, such as building a sustainable production, processing, distribution and consumption system and establishing a smart food chain (MAFF, 2023). Chongming agricultural products are mainly supplied to the Shanghai market, and the current market acceptance of organic and green agricultural products is high (Liu et al., 2019; Li and Yin, 2022). Therefore, Chongming should increase its efforts to publicize green development, thus expanding the development potential and audience of low-carbon agriculture. Chongming can create a social atmosphere that advocates low-carbon green development in this way, which is conducive to enhancing the knowledge and reputation of low-carbon agriculture in the region. In addition, it is necessary to strengthen the cultivation of agricultural talents and support the high-level development of various types of business entities engaged in low-carbon agriculture-related activities (The State Council of the People's Republic of China, 2016).

Positive carbon-enhancing circuits 1-3 corroborate the inevitability of carbon emissions during agricultural development. Increases in the scale of cultivation are often manifested in increases in the area under rice cultivation, which can lead to increases in fertilizer and pesticide use and rice's carbon emissions. Burning fossil fuels also produces greenhouse gases in the ongoing advancement of agricultural machinery production (Zhou, 2020). The increase in the scale of farming is manifested in an increase in the total volume of livestock and poultry farming. Organic materials in animal manure are decomposed by microorganisms under anaerobic conditions to produce greenhouse gases such as methane and nitrous oxide. Ruminants such as cattle and sheep produce large amounts of methane emissions through rumen microbial fermentation of sugars in feedstuffs. These can lead to increased carbon emissions from agriculture (Hamilton et al., 2010; Rotz, 2018). Therefore, Chongming should combine the world-class ecological island construction and development requirements to create a low-carbon green agriculture to match. For the plantation industry, we propose actively promoting the circular agriculture model and applying specific measures, such as the green farming techniques proposed in the reverse carbon reduction loop. In addition, fertilizer and pesticide reduction programs should be formulated according to local conditions, and the efficiency of chemical application should be continuously improved to reduce agricultural pollution and enhance soil fertility (Zhang, 2015; Liu et al., 2023; Tang et al., 2023). Finally, Chongming should achieve large-scale production through land intensification measures to reduce the average carbon emission intensity per unit of land. For the cultivation industry, it is necessary to implement scientific green farming and increase the utilization of livestock manure and other waste resources (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022c).

4 Discussion

The preceding analysis shows that Chongming has achieved remarkable results in developing low-carbon agriculture and has formed its unique development model. Chongming has unique advantages in the development of low-carbon agriculture. Chongming is located at the mouth of the Yangtze River, with harmonized climate resources and abundant water and biological resources, and its unique natural location is conducive to maintaining good ecological conditions (Wang et al., 2005). Chongming is backed by the economically developed city of Shanghai, which has a large market demand for high-value-added agricultural products (Liu et al., 2019). In addition, the Government attaches great importance to developing low-carbon agriculture and has provided policy support for its development.

Low-carbon agriculture in Chongming is also exemplary and replicable. Chongming's experience models developed in the exploration process provide examples of developing low-carbon agriculture in other regions (Ministry of Agriculture and Rural Affairs of the People's Republic of China, 2022e). Promoting the development of low-carbon agriculture through a multi-system approach of technology, policy, and markets can effectively guide subsequent practice (Luo et al., 2011). The technical standards and evaluation system for agricultural carbon emission reduction established and formulated in this process also have a demonstrative effect on the development of low-carbon agriculture.

Finally, this study explores the causal relationship of carbon emissions in Chongming's agricultural development through a system dynamics approach and puts forward relevant policy recommendations, but does not consider the impact of climate change on low-carbon agriculture. We believe that further research directions could include the resilience of low-carbon agriculture to climate change and the mitigation effects of climate change through low-carbon agricultural practices.

5 Conclusion

Low-carbon agriculture is an essential means of implementing sustainable agricultural development, and in recent years, the development of low-carbon agriculture in Chongming has achieved good results. Based on summarizing Chongming's previous low-carbon agricultural experience model, this paper analyzes the problems and challenges faced in the development process. Based on the system dynamics method, we construct the causal relationship of carbon emission in the development process of Chongming agriculture and put forward feasible path optimization suggestions. 1) Increasing policy support and financial inputs and emphasizing low-carbon agricultural technology innovation. 2) Strengthening publicity and guidance on low-carbon agriculture to broaden the consumer market. 3) Optimizing the structure of agricultural production and improving the level and quality of low-carbon agricultural development. This article provides a reference for further exploring the development of low-carbon agriculture in Chongming.

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