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# Technological Revolution in the Field: Green Development of Chinese Agriculture Driven by Digital Information Technology (DIT)

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**Abstract:** According to the Plan for Rural Development of Digital Agriculture (2019–2025), accelerated integration of digital technologies and agriculture is crucial to promoting high-quality agriculture in China. The application of DIT in agricultural activities will not only help improve the efficiency of agricultural production, but also promote the green development of agriculture and the achievement of the Dual Carbon Target (DCT). In order to further clarify the comprehensive effects of the application of DIT in agricultural systems and provide routes for government decision-makers to assist in reducing agricultural emissions by DIT, this paper adopts the logical deductive method and starts with the application status to draw out the specific paths of low-carbon transformation in DIT-driven agriculture, while further discussing the potential issues in the process and corresponding solutions. DIT is a double-edged sword. It can promote the green and low-carbon transformation of agriculture by implementing precision operation, environmental monitoring, optimizing carbon emission accounting, and supervising the carbon market. However, at the same time, it may face problems such as unbalanced rural development and excessive financialization of the carbon market. Therefore, we should be optimistic but cautious about the application of DIT in reducing agricultural emissions. We can address potential problems by strengthening government-led investment, broadening channels for capital investment, strengthening skills training for farmers, and enhancing the regulation of trading in carbon sink markets.

**Keywords:** DIT; green development; agriculture; carbon emissions reduction



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## 1. Introduction

Climate change has become a common threat and challenge, and global warming has seriously affected agricultural production and other socioeconomic activities. In response to this serious problem, China proposed a Dual Carbon Target (DCT)—also known as carbon peaking and carbon neutrality targets—in 2020. Carbon neutrality requires net-zero emissions of GHGs (greenhouse gases, i.e., any gas that absorbs and emits infrared radiation and is present in the atmosphere. The six greenhouse gases controlled by the Kyoto Protocol are carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). However, for simplicity of presentation, we sometimes use carbon emissions instead of GHG emissions. In this article, carbon emissions have the same meaning as GHG emissions) within a specific period. From the perspective of the three industries, the primary industry, represented by agriculture, is the only one that can provide carbon capacity to absorb GHG emissions. Therefore, achieving the low-carbon and green development of the agriculture sector is an essential prerequisite for taking the lead in achieving the goal of carbon neutrality in agriculture and the nation's overall carbon neutrality.

When the DCT was first proposed in 2020, the issue of carbon neutrality quickly became a hot topic in the research field. The research mainly focuses on energy structure adjustment [1,2], carbon neutral capacity assessment [3,4], and innovations in carbon emission reduction technology [5–12]. The technologies are mainly divided into the following categories: (1) Biological carbon sequestration technology [5–7]; researchers have suggested using abandoned farmland [6] or changing grazing patterns [7] to increase carbon sequestration, and some scholars have proposed building agroecosystem models to guide future decision-making [5]. (2) Carbon capture, utilization, and storage technology (CCUS) [8–10], which captures $CO_2$ by matching [8] or combining enzymes with $CO_2$ [9]. (3) Direct air capture (DAC) [11], based on both liquid and solid forms. (4) The carbon cycle (CR) [12] refers to the recycling of carbon fiber in various ways and the manufacture of new composite materials. In addition, in the field of agriculture, the mechanism of technological progress in agricultural carbon emissions has also been discussed [13–15], including the effects of agricultural machinery technology [13] and planting progress [14,15].

With the rapid development of information technology, digital information is becoming integrated with daily life. In addition to discussing the relationships between DIT and economic development [16,17], business management efficiency [18,19], etc., the research on whether and how DIT can affect GHGs has gradually become a hot topic. Studies have found that DIT can effectively assist industries in reducing carbon emissions [20–23]. For example, the energy industry can adjust the energy supply and demand through data monitoring, optimizing carbon emission and carbon sink calculation, and reducing the carbon footprint of the energy industry by using information technology [20]. In the financial market, blockchain technology can effectively improve the efficiency of carbon trading [21,22], and the combination of information technology and financial systems can help reduce environmental pollution [18]. In enterprise management, digital technology can not only improve management efficiency but also facilitate the construction of low-carbon enterprises [23]. Nevertheless, in the field of agriculture, there are few studies directly discussing DIT and agricultural emission reduction alone. However, from the experience of developed countries, the extensive application of DIT in agriculture is an effective way to reduce carbon dioxide emissions [24]. In China, researchers analyzed a case study in the city of Chengdu in Sichuan Province and found that digital technologies can reduce agricultural $CO_2$ emissions directly through precise fertilizer application and reduced energy consumption, as well as indirectly by reducing production and operating costs and maintaining production sustainability [25].

DIT has penetrated into almost all aspects of social production and life, and agriculture is the basis of human social development. Our research aims to explore how, in addition to enhancing agricultural production efficiency [26,27], DIT can be used to reduce agricultural greenhouse gas emissions. The literature directly discussing DIT and carbon reduction in agriculture is scarce; although existing studies have confirmed that DIT has a positive effect on reducing agricultural carbon emissions, there is a lack of detailed elaboration and discussion on how DIT can assist in reducing agricultural carbon emissions, as well as a lack of risk analysis and systematic identification of the mechanism of action. Therefore, in this study, we focus on these issues and propose the implementation path, potential problems, and strategies of DIT to address agricultural carbon emission problems, in order to provide a reference for solving the current dilemma of agricultural carbon emissions in China, and to further help in achieving carbon neutrality and finding a breakthrough for the future global response to climate change.

## 2. Methodology

This study provides a comprehensive analysis of the potential role of DIT in reducing GHG emissions in agriculture, including its mechanisms, potential risks, and corresponding countermeasures, through descriptive statistics and logical deduction methods.

The structure of the analysis is as follows: The current situation and present problems are described, a -solution is proposed, and potential risks and their avoidance measures are explored. The databases involved in the study include data published by the FAO (1961–2019) and the Chinese Ministry of Agriculture and Rural Affairs (2019–2021). By conducting a descriptive statistical analysis with these data, we provide a detailed and systematic understanding of the current status of China's agricultural GHG emissions and the application of DIT in agriculture. In addition, we conducted a literature search in two databases—CNKI and WoS (CNKI is short for China National Knowledge Infrastructure, which is the world's most comprehensive online resource for accessing China's intellectual output. WoS is short for Web of Science. The retrieved studies in Chinese were obtained from CNKI, including CSSCI-indexed journals and Peking University core journals. Studies in English were obtained from WoS, including SCI- and SSCI-indexed journals)—using the keywords digital technology, information technology, and emission reduction, with 2022 as the ending time point. Based on the retrieved literature, we conducted a statistical analysis and used deductive reasoning to understand the principles of DIT to improve environmental quality or reduce GHG emissions.

Based on the authors' long-term observation of Chinese rural society and media reports from various formal channels on the application of DIT in rural areas, both domestically and abroad, we present some possible risks faced by the rural areas, the carbon sink market, the government, and enterprises in the DIT-driven GHG reduction process in agriculture according to the basic principles of economics and social dynamics. Finally, corresponding suggestions are made for various stakeholders, such as government, research institutions, information service companies, and farmers' organizations, to provide a theoretical basis for DIT-driven agricultural GHG reduction.

## 3. Current Status of Digital Information Technology in Low-Carbon and Green Development in Agriculture

The green development of agriculture includes six aspects: agricultural layout, resource utilization, agricultural production methods, agrarian industry chain, agricultural product supply, and agricultural product consumption [28]. The low-carbon and green development of agriculture requires effective control of carbon emissions in production. During the production process, monitoring technology can establish an accurate and timely data feedback mechanism to provide agriculture-related departments with evidence of carbon reduction actions.

At present, China's agricultural carbon emissions are still at a high level. According to data released by the United Nations Food and Agriculture Organization (FAO), China's total carbon emissions from the agricultural sector have been on an overall upward trend from 1961 to 2019. Agricultural carbon emissions totaled 0.599 billion tons in 1961, which increased to 1.326 billion tons in 2019—nearly 2.2 times the level of 1961. China is continuously trying to apply DIT to agriculture. Along with the popularization of the Internet in rural areas and the maturation of modern DIT such as 5G and drone technology, the application of modern DIT in agriculture for production and management is becoming more common. However, due to the characteristics of the technologies and some management factors, the application of DIT in the field of agricultural emission reduction is relatively slow, and the effect is not yet ideal in China.

(1) The application of digital information technology in China's low-carbon and green agricultural development started late, and there are significant geographic disparities in the technology's adoption. China is a giant traditional agricultural nation. Although China has a long history of agriculture, it is not a mighty agricultural power. China still has a gap with modern agricultural powers such as Germany, the USA, Australia, Japan, etc., especially in DIT applications in agriculture. According to The National County-level Agricultural and Rural Informatization Development Level Evaluation Report (2019–2021) issued by China's central government, the national agricultural production informatization level in 2020 was only 22.5%, and the national agricultural product quality and safety traceability informatization level was 22.1% (see Tables 1 and 2 for detailed data). However, as early as around 2016, Australia [29,30] and other developed countries began to lay out their

Agriculture 4.0 strategies featuring digital technologies. Moreover, the abovementioned report also notes that in 2019, the national environmental monitoring of green food production areas accounted for only about 10% of the arable land area. The informatization level is not a steady-state process of continuous improvement. There are fluctuations in the production informatization levels of livestock production, field cultivation, facility production, and aquaculture, but the informatization level of agricultural product quality and safety traceability is increasing (see Tables 1 and 2 for detailed data). There is a large gap between China's realistic level of informatization and the goal of agricultural modernization. Studies have shown that the proportion of new agricultural business entities that apply digital information technology to the main chain of farming, planting, management, and harvesting accounts for less than 1/3 of the total number of agricultural business entities in China [31].

**Table 1.** Agricultural production informatization levels in 2018–2020.

| | Livestock and Poultry Farming | Facility Cultivation | Field Planting | Aquaculture | Total Agricultural Production |
|---|---|---|---|---|---|
| 2018 | 19.3% | 27.2% | 16.2% | 15.3% | 18.6% |
| 2019 | 32.8% | 41.0% | 17.4% | 16.4% | 23.8% |
| 2020 | 30.2% | 23.5% | 18.5% | 15.7% | 22.5% |

Source: The National County-level Agricultural and Rural Informatization Development Level Evaluation Report (2019–2021).

**Table 2.** Informatization levels of agricultural product quality and safety traceability in 2019–2020.

| | Livestock and Poultry Farming | Facility Cultivation | Field Planting | Aquaculture | Total Product Quality and Safety Traceability |
|---|---|---|---|---|---|
| 2019 | 21.7% | 27.8% | 13.1% | 18.5% | 17.2% |
| 2020 | 28.3% | 29.7% | 16.6% | 24.5% | 22.1% |

Source: The National County-level Agricultural and Rural Informatization Development Level Evaluation Report (2019–2021).

Another problem is that China is a large nation with 34 province-level administrative regions. Each area treats the agricultural industry differently and has significant differences in agricultural technology inputs and adoption due to their different agricultural bases and resource endowments. Generally speaking, the eastern coastal regions have a higher rate of adopting agricultural technology and are more open to new technologies. In contrast, inland areas are relatively conservative, while some remote inland agricultural areas with poor infrastructure are still blank in the application of DIT due to limitations of hardware facilities and financial resources [32].

(2) More accurate monitoring and calculation of agricultural carbon emissions and carbon sink production is the basis and starting point of all carbon emission statistics and carbon sink trading work. However, China has not yet established a perfect agricultural carbon monitoring system. The main reasons are as follows:

First of all, dispersed agricultural activities are challenging to monitor. Most agricultural production practices occur among small-scale family agricultural producers due to China's topography and land policy, except in Northeast China, Xinjiang, and the central and eastern plains of China, which have concentrated and continuous large-scale agricultural production conditions. Thus, at the level of the smallholder farmer, it is not easy to obtain accurate data, due to the enormous cost of monitoring infrastructure. Secondly, there is no officially certified systematic accounting system for agricultural carbon emissions. There is no unified official standard for the calculation method, product classification, or energy emission coefficients used for measuring carbon emissions in China [33], resulting in no unified standard for calculating agricultural carbon emissions. Third, there is still a technical bottleneck in the monitoring technology, and the current monitoring resolution is relatively low. The current quantitative remote sensing technology applied to carbon monitoring still suffers from low resolution, which makes it challenging to monitor non-$CO_2$ GHG accurately; therefore, accurate carbon emission data cannot be automatically obtained through monitoring [34].

(3) There is a gap between various types of agricultural data, which is not conducive to the application of new technologies. Big data, cloud computing, blockchain, and AI all require large amounts of data as their primary raw material to function. However, basic agricultural data collection channels are currently scattered, and the collection content, format, and accuracy standards are diverse. Agricultural data collection is usually for scientific research purposes or the needs of short-term projects, so the data are defective in terms of abundance and density. Agricultural data collected based on research and short-term projects are challenging to connect with one another and promote data linkage and sharing. Therefore, the application of DIT in the field of reducing agricultural carbon emissions is restricted by the imperfection of basic agricultural data.

In summary, there is still much room to improve the level of agricultural informatization in China, and there is a need to promote digital information technology to play its due role in the green transformation of agriculture. Since the introduction of the DCT, the task of reducing carbon emissions has become urgent. Making good use of the existing DIT to reshape the modern agricultural system is the key to the successful modernization and green development of agriculture in China.

## 4. Exploration of the Path to Low-Carbon Agriculture Empowered by Digital Information Technology

The essence of DIT applied to low-carbon and green transformation in agriculture is the process of continuously collecting, processing, and applying data. The 3S technology can be used for carbon emission monitoring of crop growth and livestock farming, as well as precise management of agricultural facilities. The emerging digital information technology represented by big data and blockchain will be available for instant calculation and prediction of agricultural carbon emissions, carbon sink trading, carbon footprint tracing of agricultural products, regional carbon emission hotspot prediction, and many other applications.

In short, the use of DIT to achieve comprehensive automatic collection and processing of data from the whole agri-industrial chain and to forecast the trends of agricultural carbon emissions with high confidence will significantly help in achieving the DCT in the future. Figure 1 shows the basic principles of DIT to help achieve low-carbon and green development in agriculture. The 3S technology acts as a sensor and monitor to collect the data of agricultural production and environmental changes, which are transmitted to big data and blockchain through Internet tools for the processing, analysis, and storage of data.

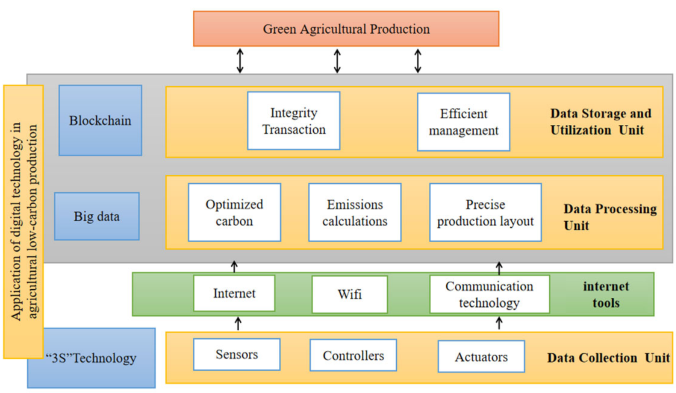


**Figure 1.** The general idea of digital information technology enabling the transformation of low-carbon green agriculture.

*4.1. Reducing GHG Emissions through 3S Technology*

Geographic information systems (GISs), the Global Positioning System (GPS), and remote sensing (RS)—known as 3S technology—can be used in monitoring land changes, crop growth, farmland environment, biomass, and even the GHG emissions from crops or animals. Moreover, these technologies can achieve optimal path planning and autopilot through their positioning and navigation function and, in turn, reduce GHG emissions as a result of fuel savings. Therefore, 3S technology can be seen as a critical tool in modern agricultural development and reducing carbon emissions in the context of the DCT. Relatively speaking, 3S technology is representative of agricultural information technology and is the first information technology used in agriculture to make the production process more efficient [35]. See Figure 2 for details about the use of 3S technology to promote reductions in agricultural emissions. RS monitors crop growth, forest cover, and other raw data; GPS is used to obtain geographical location information; and both systems transmit data to the GIS to form a dataset. Based on the datasets, the GIS issues instructions for data analysis, precision agriculture, pollution control, etc.

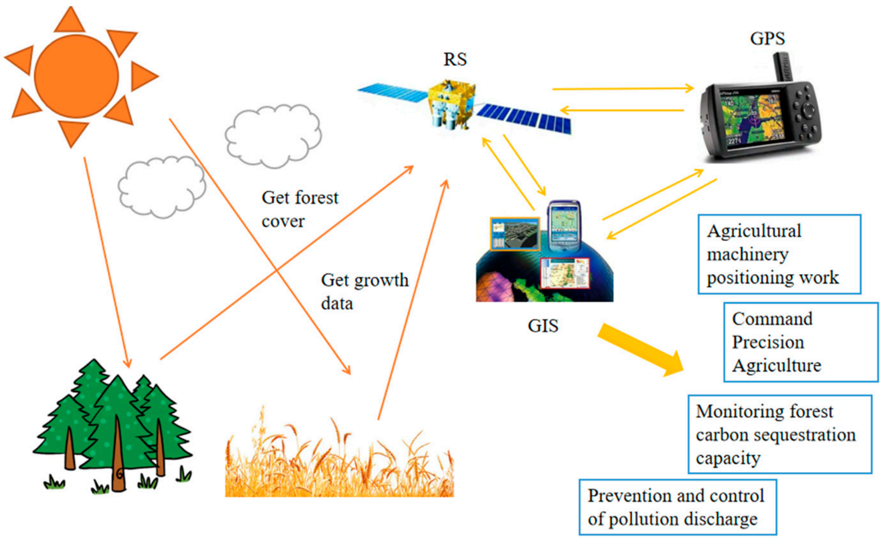


**Figure 2.** The implementation path of “3S” technology to help agricultural carbon reduction and carbon sequestration.

4.1.1. Implementing Precision Agriculture to Reduce Unnecessary Carbon Emissions

From the technical point of view, precision agriculture as we know it today is mainly achieved by GISs, GPS, and RS, and the application of these technologies plays an essential role in improving agricultural production efficiency and protecting the ecological environment. Specifically, the contribution of 3S technology to reducing carbon emissions in agriculture includes the following points:

Accurate detection of the usage of agricultural materials can avoid carbon emissions caused by the abuse of agricultural inputs. As a command center, the GIS combines crop growth and environmental data obtained by RS to form a compound dataset that provides information on fertilizers, pesticides, and water usage. Referring to the optimal amounts of material inputs for crops and cooperative use of automated fertilizer, pesticide, and irrigation devices, farmers’ empirical planting can be transformed into a standardized planting scheme. Such a shift would reduce carbon emissions while maintaining yield and production efficiency.

Positioning and travel route planning of agricultural machinery can reduce extra energy consumption and carbon emissions. GHGs from crop cultivation, livestock farming, and agricultural machines are the main components of agricultural GHG emissions [36], and the carbon emissions from agricultural machinery deserve particular attention. The GPS provides an accurate location for agriculture machinery’s operation. The operation is monitored and controlled according to the pre-stored geographic information and the optimal travel route of the farmland. The machines can reduce energy consumption and carbon emissions by moving along the set path. According to the Agricultural Growers Resource Organization (AGRO), the precise operation of agricultural machines in Australia can save 10–40% of production costs and more than 20% of energy consumption by avoiding ineffective mechanical movements [37].

The integrated use of 3S technology helps to solve the problem of land fragmentation. With the assistance of RS, GISs, and other technologies, it is easy for land management departments to carry out activities such as land resource surveys, land planning, and land consolidation. Consolidated land saves a lot of unnecessary energy consumption due to the land ownership barrier. Overly fragmented plots based on ownership will result in the machines' frequent crossing of different operating areas, resulting in additional energy consumption. Some scholars compared the carbon emissions of farm machinery operations before and after land consolidation projects and found that the consolidated land saved more than 21 t of diesel fuel per year in field transportation and reduced carbon emissions by nearly 13 t per year compared to the fragmented plots; this scaled operation method could reduce the carbon emissions by a maximum of 86.7% [38].

#### 4.1.2. Improving Monitoring Efficiency and Reducing Unnecessary GHG Emissions

The ecological and environmental departments play a leading role in efforts to reduce GHG emissions, and RS technology is their most powerful tool. The earliest mention of RS technology was in the Common Agricultural Policy of the EU countries in 1988; it was mainly responsible for measuring the land area and predicting food production, and then in 1993 the EU countries extended its application to agricultural monitoring [39]. After years of development, the application of RS technology expanded to different aspects.

The ecological and environmental department uses a combination of satellite remote sensing, unmanned aerial vehicle (UAV) remote sensing, and ground remote sensing to detect pollution of the atmosphere, water, and soil in agricultural production. At the same time, it can also monitor sudden meteorological disasters and prevent forest fires. Fire departments can use the thermal infrared band to detect the fire spots of the area in time. The ecological and environmental department can determine the location and quantity of GHG emissions from farmland through the optical properties of GHGs and implement timely countermeasures. In addition, combined with air pollution data inferred from aerosol theory and inversion algorithms [40], RS technology can also monitor and constrain GHG emissions from livestock production in real time.

#### 4.1.3. Dynamic Monitoring of Forest Trees to Assess Carbon Sequestration Capacity

Real-time monitoring by 3S technology helps to assess and respond to forests' carbon sequestration capacity in real time. Carbon sequestration includes both physical and chemical sequestration. Among them, carbon sequestration through forests' vegetation, soil, and biosphere is a typical mode of carbon sequestration. Forest ecosystems influence the global carbon balance, and the carbon storage capacity of forests makes forestry a key component of carbon neutrality. RS technology and GISs provide the most powerful technical support for measuring GHG emissions and assessing forests' carbon reduction and soil sequestration capacity. The measurement of forest biomass is a prerequisite for estimating forest carbon sinks. The advent of RS technology has made biomass measurement fast and economical. One method is to use optical remote sensing, synthetic aperture radar, light detection and ranging RS, and multisource RS to dynamically the monitor vegetation cover, vegetation index, and leaf area index in real time to determine the forest biomass accurately [41]. By multiplying the total biomass of the observed area and the carbon-absolving coefficient of each plant, we can determine the carbon sink of the forest. Another method is referring to RS images, meteorological data, and adjusted carbon density data to estimate the vegetation carbon sink through mathematical models [42].

### 4.2. Reducing GHG Emissions through Big Data Technology

Accounting for agricultural carbon emissions involves data collection and utilization of multiple systems, which is a very complex task. The emergence of big data technology based on the development of computers and the Internet can significantly simplify this task. Real-time data collection and calculation shorten the calculation process and improve the accuracy of accounting by eliminating the influence of human errors. Shortening the process from data collection to emission calculations can contribute to the efficiency of green production decisions. For details, see Figure 3. Big data can optimize the calculation method of carbon emissions through massive data analysis and predict the exact time of carbon peaking and carbon neutrality, providing data support for the market.

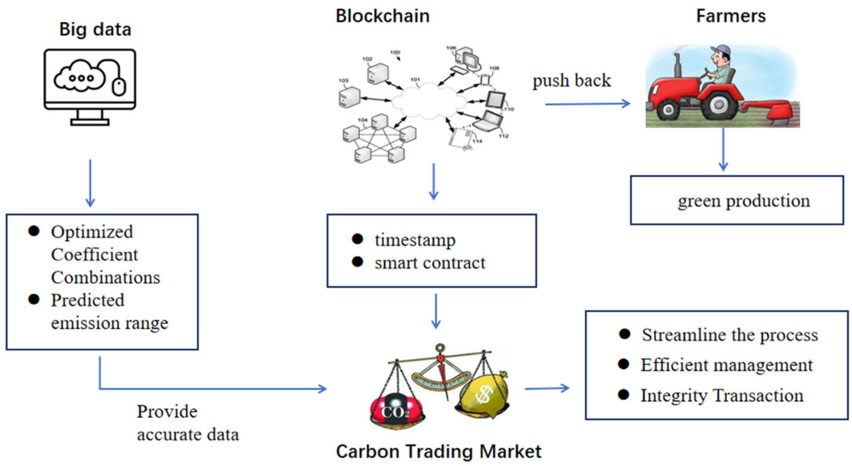


**Figure 3.** How big data and blockchain technology help reducing agricultural carbon emissions.

#### 4.2.1. Big Data Can Optimize GHG Emission Calculation Methods and Accurately Predict Carbon Peak and Neutrality

Big data technology can optimize carbon emission calculations and predict carbon peak and carbon neutrality. Due to the uncertainties of technological and economic changes, relying on traditional statistical methods to accurately predict the carbon peak and carbon neutrality is not easy. Therefore, it is also not easy to propose the correct practical route with certainty. Using the powerful collection and analysis ability of big data and AI technology for massive data, we can reduce human intervention, enabling timely analysis and monitoring of the trends of regional GHG concentration. Then, we can turn the traditional regular retrospective calculation into a real-time calculation.

With the help of big data and AI technology, we can achieve accurate agricultural GHG calculations according to the characteristics (e.g., GHG emission coefficient) of different agricultural products and their different energy consumption in the production process. We can also build a simulation system with a large amount of data and high computing power to predict energy use and production material consumption under specific scenarios of agricultural economic development. Under such technical conditions, the schedule for the DCT will become more accessible.

#### 4.2.2. Big Data Technology Allows for Precise Green Production Planning

Big data technology can integrate the collection and accounting of carbon emissions data into an automated and real-time calculation process, which provides the primary conditions for making green production arrangements quickly. Using big data and AI to collect and analyze massive data can largely avoid human errors. Furthermore, the conventional retrospective calculation of carbon emissions can be transformed into a real-time calculation and prediction. Such processing of agricultural data can accurately predict the changes in carbon emissions from agricultural production and determine the best plan of low-carbon and green agricultural production for decision-makers through computer simulation. Of course, big data technology can not only calculate agricultural carbon emissions in real time and predict the trend of agricultural carbon emissions, but it can also predict the agricultural economy's short-term and long-term development trends, with the ability to have a large throughput of data. Thanks to big data technology, the relationship between indicators such as cost, profit, and GHG emissions of agricultural products is clear at a glance. The apparent relationship between these indicators facilitates decision-making by policymakers. Combining the data of economic and agricultural carbon emissions indicators, three decision-makers—namely, the government, agricultural production organizations, and even smallholder farmers—can take advantage of the technology and customize production decisions to maximize profits and minimize carbon emissions.

### *4.3. Reducing GHG Emissions through Blockchain Technology*

Blockchain technology is a new Internet information interaction technology closely linked with big data, cloud computing, AI, and other DIT. The encryption mechanism, distributed bookkeeping features, and consensus mechanism of blockchain can provide extremely high data reliability and excellent security for transaction activities. The characteristics of blockchain facilitate activities such as agricultural information traceability and agricultural finance which, in turn, can improve production and management efficiency and promote agriculture's green and low-carbon development. The specific implementation path of how blockchain and big data can help reduce carbon emissions is shown in Figure 3. Blockchain enables honest trading and efficient management of carbon trading markets through timestamps and smart contracts. At the same time, the irreversibility of blockchain could force the farmers to conduct green production.

#### 4.3.1. Breaking the Barriers between Platforms and Improving Carbon Trading Efficiency

Blockchain has technical features such as decentralization, openness and transparency, timestamp service, trust consensus, and smart contracts, which can effectively ensure data security, reduce transaction costs and risks, and improve transaction efficiency.

The Carbon Emission Rights Registration System (CERRS) participants can submit carbon quota demands and other information to register in the Carbon Trading Blockchain Network (CTBN) according to their node types. After verification, the authority then issues a digital certificate to the participants, which serves as a unique identity for the entire network. In this way, the CERRS in different countries and regions can become a registration system to undertake the functions of carbon emission rights verification, registration, and transaction settlement. These different markets in different regions can become a unified market through blockchain. On the one hand, CERRS connects to the emission reporting system, which can quickly obtain the emissions data of relevant enterprises, conduct data verification, and support carbon quota allocation and compliance. On the other hand, the CERRS docks with the carbon sink trading system and clearing banks to provide trading changes of carbon assets, asset confirmation, and fund settlement services.

The function of carbon emissions reduction and investment in the carbon sink market (The carbon sink market literally means a place where carbon sink assets are traded. What is actually traded in the carbon sink market is carbon emission allowance or carbon emission rights. Companies with carbon emission allowance balances sell their excess emission allowances in the market. In contrast, companies with excess carbon emissions need to obtain carbon emission rights by purchasing additional carbon emission allowances to meet their production needs, or they will be shut down. Such trading helps encourage carbon-emitting enterprises to reduce their carbon emissions. The subject matter of carbon sink market transactions is also often referred to as carbon sinks; therefore, in this study, we use the carbon sink market to represent the place where carbon emission allowances are traded.) will become easier with the help of blockchain technology. Convenient transactions will make the market active and prosperous. Since the transaction objectives in the carbon sink market are from agriculture, blockchain will significantly but indirectly promote the formation of more carbon sinks in the agricultural sector, making room for carbon emissions from other industries.

#### 4.3.2. Creating a Pushback Mechanism to Promote Low-Carbon Green Behavior

Blockchain can record detailed information about every step of agricultural production. Consumers' concern about this kind of information can force the production process to become green and low-carbon.

The emergence of blockchain dramatically improves the current situation of inaccurate commercial information on agricultural products. The use of social media to sell agricultural products online has become a popular and effective sales method in recent years. According to statistics, the online sales in rural areas of China accounted for CNY 1.79 trillion in 2020, and the rural e-commerce market of China could reach CNY 3153.3 billion [43]. It is usually difficult to obtain quality assurance for the agricultural products sold privately in rural areas, especially under the standard of green production. The credit rating and purchase reviews from buyers become the leading reference indicators for new consumers to decide whether to buy or not. Unfortunately, merchants' credit ratings and purchase reviews can be tampered with through illegal means. With no guarantee of essential quality, it is even more challenging to guarantee the green production of agricultural products. Despite the legal and institutional constraints, large-scale agricultural producers, driven by profit, still have insufficient incentives to engage in green production. They can still conceal or tamper with crucial information about their products through illegal means.

Blockchain makes it difficult to tamper with the recorded data through distributed bookkeeping, digital encryption, and consensus mechanisms. Thus, a blockchain system can preserve the original information in the production process of agricultural products to the maximum extent by using devices such as cameras and detectors for chemicals, temperature, and humidity, without any human error—including operational errors and intentional acts. Once agricultural producers (e.g., smallholder farmers or large-scale enterprises) enter the officially recognized blockchain system, the information generated by their activities and shown to the public is entirely trustworthy.

The input records of pesticides, fertilizers, antibiotics, and other elements recorded by blockchain are more credible than those of traditional systems purely for data logging, and agricultural products that use a lot of pesticides and fertilizers will have nowhere to hide. Blockchain technology exposes the actual attributes of agricultural products to consumers. It allows them to vote with their feet, thereby reversely paving the way for producers to take the initiative to produce green agricultural products.

### *4.4. New Technology Is a Double-Edged Sword*

Every coin has two sides, and we should be vigilant to the potential risks of technical failure and moral hazard. Since it takes time from the appearance of new technologies to their maturity, there are inevitably some loopholes and bugs in the process of the technology's operation itself and the integration and application of new technologies in reducing agricultural carbon emissions.

Promoting and applying new technologies also requires user education, which means time and economic costs. Therefore, if a technology that is beneficial to agricultural carbon reduction cannot achieve economic benefits in a short time, it may be killed by the market. New technologies may be hijacked, attacked, and/or maliciously used by hackers. Therefore, the protection capabilities of new technologies—especially digital agricultural emission reduction projects based on one or more technologies—must take measures to prevent hacking.

In addition to the possible imperfections of the technology itself, moral hazard is a huge challenge in applying new technologies. The moral hazard of the use of DIT includes two aspects: On the one hand, there is the risk of being maliciously attacked, hijacked, and exploited by the criminals mentioned above. On the other hand, there is the moral hazard of technology providers and the moral hazard of owners who master their business conditions based on the specific technology. Technology providers may sell user data for commercial interests, violating the basic ethical requirements of user data confidentiality. These data leaks can expose users to harassment or malicious competition from peers. Such cases of selling user data are not uncommon today. Those producers who obtain factual information through DIT can conceal their actual situation for commercial interests, since the vital information is the key to decision-making for consumers or investors. In order to avoid stock price fluctuations, some listed companies will selectively report their financial statements in order to mislead consumers and investors. Concealment of actual business status may lead to the failure of the mechanism for pushing back on green agricultural production. The intervention of DIT, such as AI auditing, may help to solve such problems, but the moral hazard from agricultural producers is still difficult to avoid.

## 5. Potential Problems and Solutions of the New Technologies

The arrival of the digital age is unstoppable. The emergence of advanced technologies can and should be actively and widely applied to reduce agricultural carbon emissions and help to realize the green development of the whole society. In the era of DIT explosion, reducing agriculture's GHG emissions and fostering green development will become inseparable from DIT. However, it is undeniable that the diffusion and use of new technologies can also put pressure on the participants of green agricultural production for some non-technical reasons.

### *5.1. Potential Problems May Be Encountered in the Application of New Technologies in Agriculture*

(1) Through the previous analysis, we can understand that DIT can contribute to reducing agricultural GHG emissions in general. However, due to differences in resource endowments, economic bases, and hardware facilities in vast rural areas, the use of DIT may lead to the emergence of the technological "Matthew Effect".

Rural areas with better primary conditions are more attractive to new technologies [44], because they have good conditions in terms of transportation, capital reserves, technological reserves, and propensity to use new technologies. In this way, rural areas with first-mover advantages will always maintain their advantages and will continue to widen the gap with less-developed areas in the level of DIT application and the level of reduction in agricultural GHG emissions.

The emergence and rapid iteration of new technologies makes it difficult for traditional agricultural practitioners to meet the needs of modern agricultural production. The use of DIT in agriculture has certain learning costs and technical thresholds. According to China's Third Agricultural Census in 2016, about 80% of the people engaged in agricultural production and business activities in China are above 36 years old, and about 20% are above 55 years old. More than 70% of those engaged in agribusiness have a junior high school education or below [45]. These data indicate that there are barriers to spreading and popularizing information technology in rural areas. For agricultural practitioners, the onslaught of the new technology wave will eliminate traditional agrarian producers who cannot adapt to the new situation and technology. As farmers in developed rural areas are more educated, pioneering, and innovative, these areas with more educated farmers will have a greater chance of achieving great success using new DIT.

(2) Digital information storage and processing equipment are expensive, and the initial capital investment is enormous. The development of data acquisition and processing technology requires database construction as the foundation. Moreover, database construction, operation, and management will increase the cost, which is undoubtedly a financial pressure for the database investors. In addition, the data collection, storage, processing, and preservation process requires a large amount of equipment, which needs a lot of power consumption. Constant temperature and humidity requirements for facilities' environments lead to higher maintenance costs and a large amount of energy consumption, labeling these databases as environmentally unfriendly, contrary to the intent of green

development. According to statistics, agricultural DIT is the least attractive to the social investment of all industries. From 2010 to 2015, investment in digital agriculture accounted for only 1/5 of financial sector investments [46]. Therefore, the construction of agricultural informatization needs the government and relative departments to step in and play the leading role by providing policy and financial support.

The operational foundation of DIT requires many upfront investments that are difficult for small-scale enterprises and individuals to afford. To maintain their leading market positions and economic interests, large technology enterprises have strong incentives to create technology monopolies, which hinder the diffusion of technology and cause the welfare of technology demanders and society to suffer. The worst-case scenario is that the GHG reduction targets will fail once the government and such technology monopolies begin to collude, which will further impact the welfare of technology demanders and society. This worst-case scenario is more likely to occur in countries that are vulnerable to the influence of large conglomerates.

(3) The global market of carbon sinks based on DIT may become a new profit-seeking field of capital. The carbon sink market, initially designed for reducing carbon emissions, will be weakened. Along with the emergence and application of DIT, transactions in the carbon sink market will become easier and faster. The emergence of local markets and the gradual formation of a unified international market will make carbon sink transactions one of the essential tools in the global response to climate change.

The keen sense of capital will not let go of any profit-seeking opportunities. As major global financial markets are affected by geopolitical crises and COVID-19 epidemics, hot money is flowing out in large quantities in search of new investment markets. Moreover, the carbon sink market provides the perfect place for hot money to go. This trend is cause for alarm.

When a large amount of capital enters the carbon sink market, it may make the carbon sink price, supply, and demand deviate significantly from the actual situation, and the carbon sink will become a purely financial instrument. The price of the carbon sink will lose its adjustment function. Enterprises in need of carbon sinks will give up purchasing the carbon sinks due to their high cost which, in turn, will affect production in the real world. This price transmission mechanism from the financial market to the real economy may lead to the failure of carbon emission reduction and shrink the real economy. Thus, technological advances may indirectly increase the speculative risk in the carbon sink market.

We may not be able to say that digital information technology will directly turn the carbon market into a place for capital to make profits. However, if the market is managed poorly, the new information technology may become an accomplice to capital's murder of the carbon sink market.

### *5.2. Possible Solutions to the Potential Problems*

(1) Use technology to close the technology gap between developed and developing regions, and strengthen the training of agricultural practitioners.

In response to the possible technological Matthew Effect, we must acknowledge that China is a vast country with objective regional differences. For historical reasons, it is difficult for developing regions to reach the level of developed areas. The gap between developed and developing areas will always exist. Therefore, investment in infrastructure in the backward regions will remain an essential and ongoing aspect. Developing regions can utilize policy support in the overall national strategic layout. They can develop local resources with comparative advantages and avoid the technological Matthew Effect by using technology, i.e., taking advantage of high-speed Internet, cloud computing, and other high-end technologies to fill the technology gap between developing and developed regions. The Channel Computing Resources from the East to the West (CCREW) project was launched in early 2021, whereby China plans to build a new computing power network system that integrates data centers, cloud computing, and big data [47]. China plans to use the relatively inexpensive power advantage of the western region to absorb the demand for computing power in the east. Such an approach will not only produce large amounts of electricity from wind, solar, and water power in Western China, driving local economic development, but also achieve an increase in computing power at a lower economic cost, indirectly promoting the application of new digital technologies in various fields. Of course, such a layout will eventually show its benefits in reducing agricultural emissions.

Although China's western region is relatively backward economically, it is still rich in natural resources. Due to its abundant water, wind, and solar resources, on the one hand, the western region can obtain clean energy at a lower cost, which itself contributes to the energy industry reducing GHG emissions. On the other hand, relatively cheap electricity and energy prices can reduce the cost of digital technology applications, e.g., the CCREW project. For cost reduction reasons, numerous Internet companies have arranged their databases and servers in the provinces of Yunnan and Guizhou in Southwest China, including internationally renowned Internet companies such as Apple and Alibaba.

Focusing on training new agricultural practitioners and improving the digital information technology levels of existing agricultural practitioners is another way to deal with the technological Matthew Effect. Government departments can encourage young farmers to learn new digital technologies through various incentives, while encouraging more educated young people who are not yet involved in agriculture to enter the field. This two-pronged approach will maximize the impact of new digital information technology frontiers on agricultural operations.

With technical thresholds for older rural laborers, it is imperative to vigorously develop third-party institutions for agricultural services. Third-party agricultural service organizations composed of agricultural technicians can provide modern services at all stages, from sowing to harvesting, and the old farmers only need a small amount of input in return for higher production efficiency and product returns. Currently, third-party agricultural service organizations are flourishing in China. According to statistics, there are more than 0.9 million third-party agricultural service organizations in China [48]. The emergence of many agricultural social service organizations will significantly facilitate the application of digital technology in modern agriculture.

(2) Because of the expensive primary investment in DIT, the low willingness for social investment, the vast energy consumption of the hardware used to run the technology, and the possible technology monopolies, we believe that we can respond in the following ways:

First, GHG emission reductions and green development in agriculture have been elevated to the level of national strategy, and the promotion of this process through DIT should not rely on commercial enterprises to make infrastructural investments. The government should lead the way in providing financial investment for IT infrastructure development. Finally, because of the possibility of technology monopolies, the R&D of DIT should be mainly led and invested in by the government and supported by market development. The core technology should be in the hands of the government or state-owned enterprises. The state can provide these high-end technologies with a public benefit to the technology demanders at a reasonable price so that the technology's development and use will enter a virtuous cycle.

(3) The carbon sink market is recognized worldwide as an effective market-based instrument to cope with global climate change issues. The carbon sink market should balance the function of GHG emissions and finance through good mechanism design and appropriate government intervention to cope with the possible capital erosion risks.

The free market has a market failure phenomenon. Keynesianism economics posits that the government should actively intervene in the market in case of market failure and bring it back on the right track. As we explained earlier in 4.3.1, carbon emissions allowance is untouchable but tradable as a valuable product. This artificially defined valuable asset becomes precarious under the watch of capital and becomes a potential target for capital hunting. The original purpose of the carbon sink market—to promote reductions in GHG emissions—may become blurred or even disappear. This change in the market's intent is also a market failure, so the government must take the initiative to intervene.

In essence, the financial function of the carbon sink market is also to enable enterprises that have the will to reduce GHG emissions but do not have the sufficient economic strength to finance the upgrading of existing technologies, expand green production and, ultimately, achieve the purpose of green development. However, once the profit-seeking nature of capital amplifies the financial function of the carbon sink market, it will lead to the failure of the whole carbon market, and the GHG emissions reduction will eventually fail. Therefore, it is necessary to strictly regulate the financial activities of the carbon sink market. A laissez-faire free market will expose the profit-seeking nature of capital, and regulating the behavior of the market depends on the appropriate intervention of relevant government departments. The specific means of intervention include economic, legal, and administrative means. In addition, industry consensus and self-regulation are also essential ways to regulate market transactions. Through scientific and reasonable market mechanism design, market participants' consensus and compliance with market rules can effectively avoid the carbon sink market's excessive financialization to protect the GHG emission reduction function of the carbon sink market.

Of course, in addition to the construction of the carbon sink market itself to deal with hot money, the government should also reasonably open other types of financial markets to provide a suitable place for financial capital under the premise of safeguarding the financial system's safety. China started piloting carbon sink market trading in 2011 in seven cities and established a unified national market in 2021. China's carbon sink market trading is still in the developing stage. There will inevitably be some problems in its development and integration with the international carbon sink market. These issues include those from both inside and outside of the market. In short, market organizers (government) and market participants (companies needing the carbon sinks) must face the inevitable new problems together and explore solutions hand in hand.

## 6. Discussion

### *6.1. Realistic Necessity Discussion and Research Comparison*

In this study, we discussed a technological revolution happening in China's fields that can help to reduce the GHG emissions from agriculture. Specifically, we explained DIT's role and function in reducing agricultural GHG emissions. The representative technologies include 3S technology, big data, and blockchain. We also discussed the problems that these technologies may encounter and suggested possible countermeasures.

With the advancement of urbanization, many rural people have moved to the cities to engage in non-agricultural employment, causing a severe hollowing-out of rural China. Most of the people remaining in rural areas to engage in agriculture are older people. The younger generation of the rural population does not have basic agricultural production skills, since they have never engaged in actual agricultural production in their lifetime. Basic food security will be difficult to guarantee with the traditional agricultural economy, let alone with low-carbon development.

In the context of China's clear food security goals and the DCT, agricultural development must undergo a technological revolution. It is a huge challenge to secure food production while effectively reducing carbon emissions from agricultural production and generating more carbon sinks to make room for emissions from other industries. China's countryside and agriculture need a technological revolution to achieve these combined goals, and DIT could be at the vanguard of this revolution. DIT was not initially designed for the DCT and green agriculture. Instead, DIT has unexpectedly become a catalyst to drive agriculture towards the DCT.

There has been a proliferation of studies on technology-driven green development, ranging from discussions on technological pathways for green development in a broad industrial sense [49–52] to discussions of technology in specific fields [53,54]. All of these studies provided us with good inspiration and pathways to develop this study. Technological progress is one of the driving forces of economic and social development, and focusing resources on green technology research and development seems to be a better option to promote green development in all industries.

Some published studies on DIT and industrial carbon reduction have focused mainly on non-agricultural manufacturing industries [55] and reform in the energy sector [56]. The perspective of these studies tends to be ambitious. The few studies on DIT and agriculture have also mainly explored the relationship between DIT and agriculture from the perspective of DIT driving high-quality agricultural development [26,27].

Through the literature comparison and analysis, we found that targeted and systematic studies on DIT and low-carbon agriculture are scarce, and there is no systematic elaboration of their relationship. Our study attempts a preliminary exploration. By linking reductions in agricultural GHG emissions with DIT, we demonstrate the current situation of the application of digital information technology in agriculture, propose feasible emission reduction paths based on existing problems, and try to provide ideas for using DIT to reduce agricultural GHG emissions in China's agriculture sector.

The few cases of the application of smart technologies in sustainable agricultural development [57] already show us a picture of the future of agriculture. However, it will still take a long time for the application and diffusion of this technology; in the meantime, as explained in Section 5, inappropriate use of technology may result in losses to specific economic participants. Therefore, our approach to technology should be positive, open, and prudent. We always need to monitor and evaluate the use of new technologies.

### 6.2. Research Limitations and Prospects

Due to limited space, this paper only discusses the representative 3S technology, big data, and blockchain, and it does not conduct an in-depth exploration of cloud computing, AI, and other technologies. The essence of cloud computing is the combination of Internet software environments and hardware computing capacity, which is the carrier and a means for big data to play a role. The application of AI is more reflected in its automation and intelligence. With the development of digital technology, these information technologies will gradually enter the field of agriculture. Their role in reducing agricultural GHG emissions should not be ignored or underestimated, and their path of action also needs to be further analyzed by researchers. At the same time, our study does not deeply explore the cases of developed countries in reducing GHG emissions through DIT. The technological leadership of developed countries is undeniable, and the case studies of these developed countries can help developing countries, including China, to improve the technologies used in the field of agricultural production; such case studies of developed countries will be developed in future studies. A practical model of technological applications coupled with specific national conditions would be a useful attempt to promote digital agriculture in China.

In addition, due to the difficulty of obtaining comprehensive data, the verification of the role of multiple digital technologies in reducing GHG emissions in agriculture from the level of empirical evidence takes a relatively long time; thus, we propose a possibility from the theoretical point of view, and the subsequent empirical verification will be carried out by more scholars in the future. We will also collect more data to explore the impact of various information technologies on reducing agricultural emissions, so as to propose more targeted and practical paths for reducing agricultural emissions.

## 7. Conclusions and Recommendations

### 7.1. Conclusions

By analyzing how digital technology can solve the dilemma of green agriculture, help reduce agricultural GHG emissions, and promote the green development of agriculture, we believe that DIT, as a new technology, will play an irreplaceable role in the low-carbon and green transformation of agriculture in the future. For example, 3S technology can help agriculture achieve the DCT by improving the production efficiency of agriculture and forestry and providing more carbon sinks for trading in the carbon sink market.

Big data can help predict changes in agricultural GHG emissions more accurately and facilitate decision-makers to arrange green production. Blockchain helps to report factual agricultural GHG emission data and make the carbon sink market unveil the actual demand for carbon sinks. Furthermore, blockchain can be used to build a highly reliable agricultural information traceability system to form a production GHG emissions reduction mechanism forced by consumers' low-carbon choices. While DIT casts light on the field of reducing carbon emissions in agriculture, we should also be cautious. In applying DIT to reducing agricultural carbon emissions, there are potential problems such as high initial investment, the Matthew Effect on the regional economy, and excessive financialization of the carbon sink market. Therefore, we should maintain an optimistic but cautious attitude toward DIT.

### *7.2. Policy Implications and Recommendations*

In this study, we propose a feasible route and provide theoretical references for policy-makers. In addition, we analyze the drawbacks that DIT can bring in reducing agricultural emissions and argue that we should be optimistic but cautious about DIT. We hope that the government will fully consider these factors when using DIT to achieve the agricultural DCT in order to maximize the social benefits rather than losing sight of the other. To this end, we make the following recommendations:

Government should do a good job in top-level design and oversee DIT's assistance in reducing agricultural carbon emissions. Meanwhile, we should increase investment in digital agriculture and expand financing channels, gradually improving the degree of information technology application in China's agricultural sector to provide technical support for the next step.

Research institutions require increased research funding to attract more researchers to deeply explore the relationship between DIT and reductions in agricultural carbon emissions. More studies are needed to evaluate the effects of various information technologies on reducing agricultural carbon emissions, so as to provide the adjustment basis for decision-makers and further shorten the implementation process of agricultural DCT.

Information service companies, data analysis companies, blockchain technology platforms, network service platforms, and other enterprises and institutions should strengthen the technological research and development efforts, break technical barriers, improve the quality and efficiency of network technology services, and solve data problems more efficiently.

Peasant organizations need to increase the number of civil society organizations and strengthen skills training for farmers. The collection of agricultural data is inseparable from farmers. This is the cornerstone and key link of reducing agricultural emissions to cultivate farmers' ability to collect and process information.

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