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Can socialized services reduce agricultural carbon emissions in the context of appropriate scale land management?

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In order to achieve low carbon transformation and green development in agriculture, we analyzed the effects of different types of socialized services on agricultural carbon emissions based on provincial panel data from 2010 to 2020 in China. We further analyzed the possible ways for agricultural social services to reduce the intensity of agricultural carbon emissions with the help of mediating effect model. The results show that socialized services can provide basic services, production and operation services, financial services, and circulation services for the agricultural production chain, which can significantly reduce the agricultural carbon emissions intensity. The results of the intermediation effect suggest that socialized services can break the labor constraint by promoting the scale effect, and thus reduce the agricultural carbon emissions intensity. However, the mediation effect of technology diffusion is not significant. The reason is that although the diffusion of agricultural technology can improve the efficiency of resource utilization, the diffusion of technology also leads to the use of elements such as high concentrations of chemicals and heavy agricultural tools which may increase carbon emissions. In addition, the effect of socialized services on reducing agricultural carbon emissions intensity shows obvious spatial heterogeneity, with the reduction gradually increasing from coastal to inland provinces and from eastern to western regions.

KEYWORDS
social services, agricultural carbon emissions, scale effect, technology diffusion, sustainable development

1 Introduction

At the 75th session of the United Nations General Assembly, China committed to achieving peak carbon emissions by 2030 and carbon neutrality by 2060 (Shi and Xu, 2022; Zhao et al., 2022). In 2021, the work report of the central government also lists "doing a good job in achieving peak carbon emissions and carbon neutrality" as one of the key tasks. Agricultural carbon emissions are an important part of China's carbon emission system and have received attention from all sectors of society (Zhu et al., 2022). According to data released by the Food and Agriculture Organization of the United Nations at the COP26 climate summit in 2021, 31% of global human-made CO_2 equivalent emissions come from agricultural grain systems. Therefore, reducing carbon emissions in the agricultural production process is of great practical significance for overall carbon emission reduction (Yang and Luo, 2020), and it is imperative to promote green and low-carbon development in agriculture (Rana et al., 2021). Reasonably limiting the high-carbon behavior of agricultural production activities, actively developing low-carbon industries, and researching and developing low-carbon technologies are the key measures to reducing agricultural carbon emissions (Gorelick and Walmsley, 2020). Since agricultural carbon emissions mainly come from the fields of pesticide and fertilizer application, machinery energy consumption, irrigation electricity, agricultural film covering, and soil loss in the agricultural production process, in order to effectively reduce carbon emissions in China's agricultural production process and alleviate environmental pressure, we can optimize the agricultural production structure, transform the agricultural operation mode and reasonably develop low-carbon agricultural products (Han et al., 2018). As an important factor influencing the structure of agricultural production and business practices, agricultural social services play a vital role in agricultural carbon emissions. In 2017, The Circular on Supporting Socialized Services in Agricultural Production, jointly issued by the former Ministry of Agriculture and the Ministry of Finance, emphasized the need to cultivate "a market for socialized services in agricultural production" to "promote the green development of agriculture and the sustainable use of resources." Agricultural social services can reduce the intensity of fertilizer application, through the matching effect of operating agents and the regulating effect of factor allocation (Abatechanie, 2021). Meanwhile, it can guide the large-scale operation of land and prompt operating agents to actively and reasonably allocate modern production factors (Dessart et al., 2019). Undoubtedly, agricultural social services have become the main means and feasible path to drive modernized agricultural production. However, the role of agricultural social services on carbon emissions is not clear. Can agricultural social services reduce agricultural carbon emissions? By what means can agricultural carbon emissions be reduced? Is there regional heterogeneity in the impact of agricultural social services on carbon emissions? The exploration of the above questions has important practical significance for achieving low carbon development in agriculture and sustainable development of the economy and society (Fisher, 2020).

Therefore, the article will focus on exploring the impact of socialized services on agricultural carbon emission intensity and its transmission pathways, and further conduct empirical tests. The marginal contributions of this paper are as follows: first, while most of the previous literature focuses on the study of land scale operation, we expand the study of the mediating mechanism of service capacity of operating agents from the perspective of agricultural social services and explores in depth the mechanisms of the role of basic services, production and operation services, and financial and circulation services in reducing agricultural carbon emissions. Second, most of the existing research literature uses micro data for empirical analysis, while we empirically examine the impact of socialized services on agricultural carbon emissions based on provincial macro panel data in China. Third, we extend the theoretical mechanism of socialized services affecting carbon emission by empirically testing and analyzing the mediating mechanism of socialized services affecting agricultural carbon emission.

The chapters of this paper are organized as follows: Section 2 compares the relevant literature on agricultural carbon emissions and agricultural social services. Section 3 presents the theoretical analysis. Section 4 introduces the model variables and data sources. Section 5 reports the empirical results and their analysis. Section 6 provides the conclusion and policy recommendations.

2 Literature review

Research on agricultural carbon emissions. Studies have been conducted to study its impact on agricultural carbon emissions from various perspectives (Wu et al., 2020), including industrial agglomeration (Zheng et al., 2020), technological progress (Hao et al., 2020; Cao et al., 2021), agricultural insurance, farmland scale, and government policies (Wu et al., 2021; Yang et al., 2022). Among them, the impact of farmland scale management on carbon emissions has been studied most frequently (Ma., 20061). Agricultural land scale operation can directly or indirectly affect agricultural carbon emissions by acting on agricultural production activities (Hao et al., 2020; Liu et al., 2020). Abatechanie (2021) studied the influence mechanism of farmland operation scale on carbon emissions in terms of factor inputs, cultural quality of labor force, and financial support policies, and found that the increase of fertilizer use intensity can promote agricultural carbon emissions, and the increase of machinery input intensity has a suppressive effect on agricultural carbon emissions (Abatechanie, 2021). Tian also found that agricultural mechanization has a significant spatial carbon reduction effect, and the spatial carbon reduction effect is greater in the main grain-producing areas (Tian et al., 2014). Zhang and Zhang (2012) empirically found that scientific and technological progress has a suppressive effect on agricultural carbon emissions to a certain extent. Berhanu et al. (2021) found that CSA technology (climate-smart agriculture) can reduce greenhouse gas emissions in agricultural production (Berhanu et al., 2021). Feliciano (Feliciano et al., 2018) found that CCAFS-MOT (supporting farmers, policy advisors, and tools chosen by agricultural extension services) can reduce GHG emissions. Furthermore, in a measurement of China's agricultural carbon emissions, Yang (Yang, 2013) found that the intensity of agricultural carbon emissions has shown a continuous decline in recent years.

Research on agricultural social services. The studies that have been conducted focus on its effects on agricultural scale efficiency, agrochemical application, and agricultural technology diffusion (Nana and Kong, 2019; Xiong et al., 2018). Firstly, there are different views in the academic community on the effects of socialized services on agricultural scale efficiency (Zhao et al., 2018). There are views that agricultural social services change agricultural production methods by exerting division of labor utility, technology effect, substitution effect, and organization effect, promoting land scale operation (Hao et al., 2019; Qian et al., 2020), improving agricultural production efficiency, and realizing organic linkage between small farmers and modern agriculture. However, some argue that socialized services in China are still in their infancy, and the services still show fragmentation of farmland, isolation of links, regional differentiation, and contractual instability, and the impact on agricultural scale efficiency is not obvious. In addition, some scholars have questioned the existence of economies of scale in socialized services due to the higher transaction costs that arise when scaling up services (Hu, 2001). Secondly, the conclusions of studies on the impact of agricultural social services on agrochemical applications are controversial (Marenya and Barrett, 2009). One view is that agricultural social services have no effect on agricultural chemical application reduction and even aggravate its use (Bambio and Bouayad Agha, 2018). Another view is that socialized services have an important impact on agricultural fertilizer application and can achieve fertilizer use reduction (Ma, 2006; Huang et al., 2015). Agricultural social services can effectively reduce the use of chemical fertilizer when the socialized services organization accurately matches the new agricultural operation subject of agricultural enterprises (Diiro et al., 2021). Thirdly, regarding the impact of socialized services on the diffusion of modern agricultural technologies. Agricultural social services can significantly promote the adoption of specialized production technologies such as fertilization and pest control by farmers (Xiong et al., 2020), and the higher the participation of farmers in socialized services, the stronger the promotion of farmers' technical efficiency (Zhang et al., 2021), but there is also regional variability and farmer heterogeneity (Tian et al., 2014).

From the available literature views, it is clear that the findings on the effects of socialized services on agricultural scale efficiency, chemical inputs, and technology diffusion are inconsistent. Although the research views that agricultural scale operation, chemical input reduction, and agricultural technology diffusion are beneficial to agricultural carbon emissions are more uniform, it cannot be concluded that socialized services can reduce agricultural carbon emissions. Since there are few studies on the effects of social services on agricultural carbon emissions in the existing literature, this article aims to further explore whether social services can reduce agricultural carbon emissions and examine their mechanisms of action based on the review of previous studies.

3 Theoretical analysis

3.1 Direct impact of social services on agricultural carbon emissions

According to the principles of Marxist political economy, agricultural social services are considered to be a comprehensive service. It is used by various service institutions in society to assist agricultural production. Socialized agricultural services are used throughout the whole process of agricultural production (Zavyalova, 2022). Agricultural social services are characterized by diverse forms, rich content, and wide coverage, based on the principles of service content and scope, and synthesizing the results of existing research literature on agricultural social services, it is believed that agricultural social services include basic services, production and operation services, financial and circulation services, but their impact on agricultural carbon emissions is still unknown. Therefore, the impact of agricultural social services on agricultural carbon emissions is further analyzed. Furthermore, the transmission mechanism of the impact of socialized services on agricultural carbon emissions are shown in Figure 1.

3.1.1 Basic services and agricultural carbon emissions

Basic services are auxiliary services for agricultural production provided by government departments or socialized service organizations to farmers (Depczynski et al., 2010), such as transportation, postal communication, and information technology. Basic services run through the whole process of agricultural socialized service, which is not only the material basis for agricultural production, but also the key to sustainable service (Hu, 2001), and improving the level of basic services can reduce agricultural carbon emissions. On the one hand, government departments can achieve carbon reduction by building transportation infrastructure, standardizing the supervision and management of infrastructure, standardizing the use system of facilities, and establishing a scientific low-carbon agricultural production system by supporting the innovation and R&D of low-carbon production technologies (Rana et al., 2021) in relevant research departments. On the other hand, the national government and relevant departments can innovate agricultural production and operation organizations, alleviate the worries of agricultural operators through financial expenditure and subsidy policies, help low-carbon technologies enter the agricultural market quickly, and guide agricultural operators to use them, which can help reduce carbon emissions and promote the low-carbon transformation of agriculture. In addition, agricultural operators are often limited by production skills and knowledge when making production and management decisions, resulting in excessive chemical inputs and the use of high-emissions operations, which inevitably lead to higher carbon emissions in agriculture. Social service organizations can provide professional information on agricultural production materials (Xiong et al., 2018), agricultural production technology research and development, input and use, and agricultural technology training. They can also effectively apply modern production technologies to the agricultural production process, facilitate the learning of specialized knowledge and skills for farmers' production, and at the same time strengthen agricultural low-carbon science and technology inputs and optimize the allocation of production resources factors (Yang and Li, 2017), which can play a role in reducing carbon emissions.

3.1.2 Production and operation services and agricultural carbon emissions

Production and operation services mainly provide operation guidance in the process of agricultural production, including the supply of production materials, agricultural machinery, and business management services, and improving the level of production and operation services can reduce agricultural carbon emissions. Firstly, the problem of agricultural supply is mainly the widespread phenomenon of fake pesticides and fertilizers in the market, and agricultural operators cannot identify good and bad elements of production materials and bid for them. Social service organizations can supply and sell agricultural materials (Abed et al., 2020) and provide farmers with fertilizers, pesticides, and other elements that conform to standardized production. At the same time, social service organizations can collect and screen fertilizer efficiency information, which can provide material security for agricultural operators to identify and bargain for production materials when conducting agricultural production, regulate the use of agricultural chemical inputs, and precise fertilizer application (Abatechanie, 2021), and achieve carbon reduction through chemical input reduction. Secondly, machinery instead of labor is an inevitable trend in the future development of agricultural modernization (Zhang and Zhang., 2012), but agricultural machinery consumes more energy when operating on scattered small-scale cultivated land, which is prone to unnecessary carbon emission problems has always existed (Zhang and Zhang., 2012). Socialized service organizations can integrate farmers' land for contiguous operations, improve agricultural machinery production efficiency, and reduce unnecessary agricultural carbon emissions. In addition, socialized service organizations can purchase specialized green production apparatus, such as soil measuring instruments, and large straw crushing and harvesting machines, to provide agricultural operators with scientific and green production services. Finally, for those farmers who are less educated and lack knowledge of planting techniques, social service organizations can give farmers business guidance and other services in terms of what to produce, how to produce, and how much to produce, and provide in-depth training to farmers on chemical use, machinery fuel, and irrigation electricity, taking into account quality while ensuring efficiency (Ren et al., 2022) and reducing additional carbon emissions.

3.1.3 Financial and circulation services and agricultural carbon emissions

Financial and circulation services are a series of supporting services for the agricultural production process. Improving the level of financial and circulation services can reduce agricultural carbon emissions (Yang et al., 2021). On the one hand, the capital problem of farmers is mainly the lack of production and living funds and financing ability. Social service organizations can provide financial services, such as financing, loans, and insurance for farmers, provide financial security for farmers in the production process, help them disperse or avoid the natural and market risks encountered in the agricultural production process, improve the income of agricultural operators, and enhance their confidence in choosing an agricultural market-oriented operation. Agricultural market-based operation means catering to market consumer demand and going in the direction of green and low-carbon development. Agricultural operators supported by financial services will tend to accept technologies and business thinking related to green agricultural production and adopt efficiently, low-carbon, and green agricultural business models (Liu et al., 2020), which will help improve traditional agricultural business practices, directly reduce carbon emissions and promote green agricultural development. On the other hand, circulation services mainly include the supply of production materials and the sales storage and transportation of agricultural products, and the enhancement of agricultural products circulation services is conducive to the rapid flow of commodities to the market, the reduction of transportation costs, the reduction of vehicle circulation energy consumption, and the reduction of carbon emissions (Jiang et al., 2017). In the highly commercialized agricultural production areas, post-production processing, sales, and circulation services are the most urgently needed services for farmers. At present, the circulation of agricultural products is still in the stage of rough development, which leads to increased energy consumption and environmental pollution problems due to the lack of scientific planning and coordination, as well as the massive construction, use of refrigeration equipment, and emissions from transport vehicle exhaust. Social service organizations can effectively coordinate storage, circulation, distribution, and other links to improve the operational efficiency of logistics supply chain links as a whole (Jiang et al., 2017), and reduce the consumption of energy used by agricultural products in transportation links and carbon emissions from the loss of agricultural products themselves.

Based on the above analysis, the following hypothesis is proposed:

H1: Socialized services can reduce the carbon emission intensity of agriculture.

3.2 The indirect impact of social services on agricultural carbon emissions

Socialized services are conducive to alleviating household labor constraints and promoting the expansion of land production and operation scale (Yang, 2013). On the one hand, socialized services can reduce the search cost and supervision cost of hired labor, and solve the problem of family labor shortage. On the other hand, socialized services can replace the expensive labor factor with the relatively inexpensive agricultural machinery factor through the market mechanism, and break through the resource endowment limitation. Socialized services promote large-scale land management and realize economies of scale, that is "scale effect". The scale effect helps reduce agricultural carbon emissions, which is reflected in the expansion of land scale and the concentration of plot operations. The scale effect is also conducive to the scientific and rational use of modern agricultural production factors by agricultural operators and the reduction of agricultural carbon emissions (Liu et al., 2020). In the past, agricultural operators relied on their fathers' planting experience and knowledge of fertilization to carry out fieldwork, and due to land fragmentation and the profit maximization mentality of agricultural operators, there was usually the excessive application of pesticides and fertilizers, which caused serious soil damage and environmental pollution problems. In contrast, with the development of socialized services, service organizations have centralized and integrated fragmented land and trained agricultural operators in techniques and knowledge, such as soil testing and fertilization, which helps reduce the use of pesticides and fertilizers. Further, expanding the scale of land production facilitates field operations by agricultural machinery and improves agricultural machinery production efficiency, and reduces carbon emissions. The expansion of land production scale, will promote the field operation of agricultural machinery, increase the productivity of agricultural machinery and reduce carbon emissions.

Socialized services help the diffusion of agricultural technology in the agricultural production process, and alleviate the technical constraints of agricultural production (Yang, 2013). Social services are an important medium for the introduction of human and intellectual capital into the agricultural production process, and they can bring technical guidance to agricultural operators. When a new agricultural technology emerges, most agricultural operators benefit, while there are also barriers to its use. The emergence of new technology requires a high level of economic capacity, management ability, and knowledge of agricultural operators. Some farmers prefer to obtain relevant experience from other farmers through inquiries or observations, before adopting the technology, to avoid the risk of economic profit brought by the adoption of the new technology. But some operators are more willing to adopt new technologies and drive more people to use them through the "cohort effect". The knowledge, technology, and organizational management level of agricultural operators have an impact on agricultural carbon emissions, and this impact is stochastic (Zhang and Zhang., 2012). Agricultural technology contains two major green technologies, that aim to improve agricultural output and reduce environmental pollution. Therefore, the technology diffusion formed by agricultural social services can have an impact on carbon emissions.

Based on the above analysis, the following hypothesis is proposed:

H2: Socialized services reduce the intensity of agricultural carbon emissions through the scale effect, that is, the scale effect is the transmission path for socialized services to reduce agricultural carbon emissions.

H3: Socialized services reduce the intensity of agricultural carbon emissions through technology diffusion, that is, technology diffusion is the transmission path for socialized services to reduce agricultural carbon emissions.

4 Study design

4.1 Model construction

Drawing on the research method of Ma (2006) and Liu C et al. (2022), considering the generality of the two-way fixed effect model, which will reduce the degree of freedom

TABLE 1 Carbon sources and coefficients of agricultural carbon emissions.

Carbon source	Emission factor	Reference sources
FI	0.8956 kg/kg	T. o.West, Oak Ridge National Laboratory (United States)
PA	4.9341 kg/kg	Oak Ridge National Laboratory (United States)
AFU	5.18 kg/kg	Nanjing Agricultural University Institute of Agricultural Resources and Ecological Environment
MF	0.5927 kg/kg	IPCC United Nations Intergovernmental Panel on Climate Change Committee
ST	312.6 kg/km^2	China Agricultural University College of Biology and Technology
EFI	25 kg/hm^2	Dubey

Note: FI: fertilizer input, PA, pesticide applications; AFM, agricultural film use; MF, mechanical fuel; ST, soil tillage; EFI, electricity for irrigation.

TABLE 2 Measurement indicators and methods of agricultural socialization service level.

Guideline layer	Indicator layer	Calculation method
Basic services	Road construction level	Rural county and township road mileage (km)
	Electricity infrastructure level	Rural power generation equipment capacity km)
	Water infrastructure level	Total reservoir capacity (billion cubic meters)
	Rural postal communication ratio	The proportion of administrative villages with postal service
	Rural Internet penetration rate	Rural Internet penetration rate
	Rural communication coverage	Rural broadband access users
	Percentage of agricultural technicians	Number of agricultural technicians/total employees in enterprises and institutions
	Agricultural science and technology input level	Agricultural R&D expenditure (million yuan)
	Effectiveness of agricultural science and technology services	The number of people who obtained vocational skills certification in agricultural machinery
Production and operation services	Degree of seed supply satisfaction	Seed dosage per mu (kg)
	Licensed seed enterprises business level	The number of new licensed seed business enterprises per year
	Cost of production material services	Service cost per mu of material seeds, pesticides, fertilizers, etc. (yuan)
	Number of mechanized service organizations	Number of agricultural mechanization service organizations (a)
	Agricultural machinery maintenance point coverage	Number of agricultural machinery maintenance points/number of villages
	Rental Service Fees	Leasing service cost per mu for major crops (yuan/mu)
	The coverage rate of industrialized organizations	The number of intermediary service organizations engaged in the industrialization of agricultural machinery
	Integrated rural service level	Number of integrated rural service centers established
Financial and circulation services	Agricultural loan service level	The loan balance of rural financial institutions
	The growth rate of agricultural premium income	The annual growth rate of total agricultural insurance premium income
	Agricultural insurance payout ratio	Agricultural insurance payout and benefit amount/agricultural insurance premium
	Number of agricultural and by-product processing enterprises	Number of agricultural and by-product processing enterprises
	The total output value of agricultural and sideline products processing enterprises	The total output value of agricultural and sideline products processing enterprises (billion yuan)
	Agricultural and sideline products market trading level	The growth rate of agricultural and sideline products market turnover

estimated by the model, and considering the natural differences among different regions in China, we use the two-way fixed effect model to deeply analyze the impact of social services on agricultural carbon emissions, and the following econometric model was constructed:

$$TQ_{it} = \partial_0 + \partial_1 AS_{it} + \partial_2 X_{it} + \delta_i + \tau_t + \mu_{it} \quad (1)$$

Eq. 1, TQ_{it} denotes the carbon emission intensity of the i region in the t year, AS_{it} denotes the comprehensive level index of agricultural socialization services, X_{it} denotes the relevant control variables, ∂_i denotes the parameter estimates of the variables, and δ_i and τ_t denote the control for regional and time fixed effects respectively, and μ_{it} denotes the random disturbance term.

4.2 Variable design

4.2.1 Dependent variables: Agricultural carbon emission intensity

Referring to the studies of Deng (Deng et al., 2016), agricultural carbon emissions intensity (TQ_{it}) is expressed as the total carbon emissions of 10,000 Yuan agricultural GDP. Referring to the study of Li (Li et al., 2011), the carbon emissions from fertilizer input, pesticide application, agricultural film mulching, machinery energy consumption, soil tillage, and electricity consumption for irrigation were measured, and the sum of carbon emissions from six agricultural production processes represented the total agricultural carbon emissions. In addition, considering that agricultural social services affect different agricultural carbon sources, the carbon emission intensity of the six different carbon sources is tested for robustness to better reflect the reliability of the findings. At the same time, the regressions were conducted by taking logarithms of the explanatory variables and all other variables.

The formula for estimating total carbon emissions (TZ) is as follows:

$$\mathrm{TZ} = \sum \mathrm{TZ}_i = \sum \mathrm{T}_i \times \sum \sigma_i \tag{2}$$

Eq. 2, TZ denotes the total carbon emissions, TZ_i denotes the carbon emissions of each type of carbon source, T_i denotes the absolute amount of each type of carbon source, and σ_i denotes the carbon emission coefficient of each type of carbon source. The carbon emissions coefficients of carbon sources refer to the study of Li (Li et al., 2011), as shown in Table 1. In the data processing, all the actual values of the year are taken as the basis.

4.2.2 Explanatory variable: Agricultural socialized service level

The comprehensive evaluation index system of agricultural social services with 23 secondary indicators was condensed by synthesizing the research results of many scholars (as shown in Table 2). It takes the content of agricultural social services as the basis for selecting and dividing indicators and selects basic services, production and operation services, and financial and circulation services as the guideline layer. In addition, the selection of indicators strictly follows the principles of scientific, systematic, comparative, and accessibility. Basic services are selected as the guideline layer to reflect the agricultural production support services provided by the public sector and social service organizations for rural residents, and the indicator layer mainly includes transportation, postal communication, and information technology. Production and operation services can guarantee the normal operation of the agricultural production process and provide production guidance, management strategies, and directions for agricultural operators, and the indicator layer includes production materials, mechanization, and operation management. Financial and circulation services are supporting services for agricultural production and are crucial to the development of the regional agricultural economy, and the indicator layer mainly includes financial and insurance services and the sale and transportation of agricultural products. Finally, using Stata16 software, the entropy value method is applied to solve the weights of each index and measure the comprehensive level index of agricultural socialization services in each province.

4.2.3 Intermediate variables

1) Scale effect ($lnECO_{it}$). Referring to Yang (Yang, 2013), the level of agricultural economic development is both the main influencing factor of agricultural carbon emissions and can reflect the agricultural scale effect in each region. Therefore, the level of agricultural economic development is used to indicate the agricultural scale effect.

2) Technology diffusion (TEC_{it}). Agricultural technology diffusion can improve agricultural operators' technology reserves as well as resource utilization efficiency, thus reducing agricultural carbon emissions, and increasing opportunities and channels for agricultural operators to learn low-carbon technologies. We adopt agricultural technological progress as a proxy variable for agricultural technology diffusion and set the total output value of agriculture, forestry, animal husbandry, and fishery as an output indicator. The input indicators are set as fertilizer input use, total crop sown area, total agricultural machinery power, and the number of people employed in the primary industry. The period of the examination is 2010–2020, and the DEA method is used to measure the level of agricultural technological progress.

4.2.4 Control variables

Considering that agricultural carbon emissions are influenced by other factors, referring to Liu X et al. (2022b) and Liu et al. (2021), the final selection of indicators is related to the economic and social, and agricultural development of each region. Then use crop cultivation structure ($lnZZ_{it}$), secondary production structure (GY_{it}), tertiary production structure (TI_{it}), and financial expenditure level ($lnCZ_{it}$) as control variables. The variables were selected and defined as shown in Table 3.

4.3 Data sources and descriptive statistical analysis

The data samples used in this paper are the data of 26 provinces (autonomous regions and municipalities directly

TABLE 3 Variable selection and definition.

Variables	Name	Definition
$lnTQ_{it}$	Agricultural carbon emissions intensity	Table 1 indicator measures, taking the natural logarithm
AS_{it}	The level of socialized agricultural services	Comprehensive evaluation index system (Table 2)
$lnECO_{it}$	Scale effect	Total agricultural output per capita (yuan/person), taking the natural logarithm
TEC_{it}	Technology diffusion	Level of technological progress in agriculture
$lnZZ_{it}$	Crop cultivation structure	Food crops/non-food crops, taking the natural logarithm
GY_{it}	Secondary production structure	Value added of secondary industry (billion yuan)/GDP
TI_{it}	Tertiary production structure	Value added of tertiary industry (billion yuan)/GDP
$lnCZ_{it}$	Financial expenditure level	Agriculture, forestry, and water expenditure/general fiscal budget expenditure taking the natural logarithm

TABLE 4 Description of statistical analysis of variables.

Variables	Number	Average	SD	Min	Max
$lnTQ_{it}$	286	7.413	0.357	5.907	8.156
AS_{it}	286	0.112	0.0567	0.0260	0.398
$lnECO_{it}$	286	8.281	0.394	7.377	9.454
TEC_{it}	286	1.114	0.328	0.183	5.908
$lnZZ_{it}$	286	0.809	0.822	−0.597	3.502
GY_{it}	286	0.426	0.0706	0.193	0.620
TI_{it}	286	0.463	0.0561	0.325	0.603
$lnCZ_{it}$	286	5.433	0.857	3.288	7.142

Note: SD, standard deviation.

TABLE 5 Effectiveness of socialized agricultural services on agricultural carbon emissions.

Variables	(a)	(b)
AS_{it}	−0.529* (0.292)	−0.591** (0.246)
$lnZZ_{it}$		0.241*** (0.054)
GY_{it}		5.225*** (0.595)
TI_{it}		5.966*** (0.653)
$lnCZ_{it}$		−0.061** (0.024)
τ_t	YES	YES
δ_i	YES	YES
_cons	7.820*** (0.035)	3.070*** (0.558)
N	286	286
R-squared	0.813	0.870

Standard errors in parentheses.*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

under the central government) in China (excluding Hong Kong, Macao, and Taiwan regions of China) from 2010 to 2020. The data are obtained from the *China Statistical Yearbook, China Rural Statistical Yearbook, China Agricultural Yearbook, China Supply and Marketing Cooperative Yearbook, China Agricultural Machinery Industry Yearbook*, *National Compilation of Information on Cost and Benefit of Agricultural Products,* and the statistical yearbooks and statistical bulletins of each province and EPS database for the corresponding years, and the missing data are supplemented by the interpolation method and the neighboring mean method, and individual missing data are the index mean value. The descriptive statistical analysis of specific variables is shown in Table 4.

5 Empirical results and analysis

5.1 Baseline regression analysis

The regression results in Table 5 show the impact of agricultural social service levels in various provinces of China on agricultural carbon emissions intensity, where Table 5 (a) shows the regression results without the control variables, and Table 5 (b) shows the regression results after adding the control variables. From Table 5 (a), the estimated coefficient of the level of agricultural social services is −0.53, and it is significant at the 10% level. Both the level of agricultural social services increases by 1 and the agricultural carbon emission intensity decreases by 0.53%, indicating that agricultural socialization services can significantly and negatively affect agricultural carbon emissions intensity. As the level of agricultural social services increases, the agricultural carbon emission intensity gradually decreases, which is consistent with the previous theoretical analysis and verifies that H1 holds.

It can be seen from Table 5 (b), the estimated coefficients of secondary production structure, tertiary production structure, and cropping structure among the control variables are all significantly positive, indicating that the level of regional economic development can significantly and positively affect the intensity of agricultural carbon emissions. The possible reason is that the traditional economic development approach focuses on “increasing the volume and speed”, and the higher the level of regional industrial development and crop cultivation structure adjustment, the more energy input and the more carbon

TABLE 6 Robustness tests.

Variables	(a)	(b)	
AS_{it}	−0.396* (0.222)		
$L.AS_{it}$		−0.672** (0.263)	
$L2.AS_{it}$			−0.579** (0.266)
Control	YES	YES	YES
τ_t	YES	YES	YES
δ_i	YES	YES	YES
_cons	8.151*** (0.816)	3.248*** (0.634)	3.288*** (0.734)
N	286	260	234
R-squared	0.899	0.858	0.853

Standard errors in parentheses.*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

emission, which is more consistent with the reality. In addition, the estimated coefficient of fiscal expenditure level is significantly negative, which may be due to the incentive effect of government capital investment. The stronger the environmental awareness of farmers, the more likely they are to adopt low-carbon technologies for agricultural production, and thus reduce the carbon emission intensity of agriculture.

5.2 Robustness tests

5.2.1 New control variables are added

Referring to the existing research literature, considering that agricultural carbon emissions are susceptible to the influence of residents' wealth level, farmland operation scale, and chemical consumable input intensity, new control variables are added to the regression to test the robustness of the previous findings, and the results are shown in model (a) of Table 6. The results show that the significance levels of the regression coefficients of the core explanatory variables do not change after adding the new control variables, which proves the validity of the baseline regression results.

5.2.2 Lagged one-period and two-period core explanatory variables

Considering the time lag effect of the impact of agricultural social services on agricultural carbon emissions, the core explanatory variables are treated as lagged one and lagged two, and the model is re-estimated with the lagged variables as new explanatory variables. The test results of model (b) in Table 6 are similar to the results of the baseline regression, indicating that the model estimation results are more robust.

5.2.3 Distinguish six types of different carbon sources

Considering that agricultural social services can influence the carbon emissions intensity of different agricultural carbon sources, this paper conducts regression tests on six different types of carbon sources, and the results are shown in Table 7. The regression results show that agricultural social services have a negative and significant impact on the carbon emission intensity of the six types of agricultural carbon sources, and the test results are similar to the baseline regression results, indicating that the model estimation results are more robust.

5.3 Mechanism analysis

Based on the previous theoretical analysis, agricultural social services can influence agricultural carbon emissions intensity through two paths: "scale effect" and "technology diffusion". Based on this, an empirical test is conducted, and the following econometric model was constructed:

$$TQ_{it} = \partial_0 + \partial_1 AS_{it} + \partial_2 X_{it} + \delta_i + \tau_t + \mu_{it} \tag{3}$$

$$M_{it} = \beta_0 + \beta_1 AS_{it} + \beta_2 X_{it} + \delta_i + \tau_t + \mu_{it} \tag{4}$$

$$TQ_{it} = \gamma_0 + \gamma_1 AS_{it} + \gamma_2 M_{it} + \gamma_3 X_{it} + \delta_i + \tau_t + \mu_{it} \tag{5}$$

where M_{it} represents the mediating variable and the other variables are defined in line with Eq. 1. Table 8 models (a)–(e) is based on the principle of stepwise test regression coefficient method, and the model is tested for mediation mechanism. If the regression coefficients satisfy the

TABLE 7 Robustness tests.

Variables	FI	PA	AFU	MF	ST	EFI
AS_{it}	−0.538** (0.251)	−0.635* (0.351)	−1.041*** (0.263)	−0.352 (0.386)	−0.386 (0.253)	−0.460** (0.223)
Control	YES	YES	YES	YES	YES	YES
τ_t	YES	YES	YES	YES	YES	YES
δ_i	YES	YES	YES	YES	YES	YES
_cons	1.839*** (0.570)	−0.102 (0.797)	0.432 (0.597)	2.861*** (0.877)	−2.197*** (0.575)	−1.938*** (0.505)
N	286	286	286	286	286	286
R-squared	0.872	0.854	0.784	0.725	0.853	0.848

Standard errors in parentheses.*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

TABLE 8 Mechanism analysis.

Variables	Direct effect	Scale effect		Technology diffusion	
	$lnTQ_{it}$	$lnECO_{it}$	$lnTQ_{it}$	TEC_{it}	$lnTQ_{it}$
	(a)	**(b)**	**(c)**	**(d)**	**(e)**
AS_{it}	−0.591** (0.246)	0.488** (0.189)	−0.0968 (0.156)	0.555 (0.795)	−0.587** (0.246)
$lnECO_{it}$			−1.012*** (0.052)		
TEC_{it}					−0.00844 (0.020)
Control	YES	YES	YES	YES	YES
τ_t	YES	YES	YES	YES	YES
δ_i	YES	YES	YES	YES	YES
_cons	3.070*** (0.558)	13.63*** (0.430)	16.86*** (0.791)	1.574 (1.805)	3.083*** (0.560)
Sobel test		−0.899** (0.351)		−1.239*** (0.358)	
Bootstrap test (ind_eff)		−0.397*** (0.146)		−0.0573 (0.153)	
Bootstrap test (dir_eff)		−0.899** (0.394)		−1.239*** (0.432)	
N	286	286	286	286	286
R-squared	0.870	0.901	0.949	0.163	0.870

Standard errors in parentheses.*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

conditions: 1) ∂_1, β_1, and γ_2 regression coefficients are significant, and the value γ_1 decreases compared to the ∂_1 regression coefficient, there is a partial mediating effect; 2) the above conditions are satisfied and the γ_1 regression coefficient is not significant, then there is a full mediating effect.

Table 8 shows the results of the mediation mechanism test. From models (b) and (c), the estimated coefficients of the level of agricultural social services on agricultural scale operation are significantly positive, indicating that the scale effect is realized by agricultural socialization services. Controlling for other variables, the estimated coefficients of the scale effect on agricultural carbon emission intensity is significantly negative, and the estimated coefficients of agricultural social services are not significant, indicating that the scale effect plays a fully mediating role. Similarly, from models (d) and (e), it can be seen that the direct effect of the level of agricultural social services on agricultural technology diffusion is not significant, and technology diffusion does not play a mediating role. To ensure the robustness of the mediating effect test results, the article also uses Sobel and Bootstrap methods to test the significance of the mediating effect.

Table 8 (c) shows that the estimated coefficient of scale effect is significantly negative, indicating that enhancing the level of agricultural social services contributes to the expansion of the agricultural operation scale, and helps reduce the intensity of agricultural carbon emissions. Although the estimated coefficient of technology diffusion in the model (e) is positive, it does not pass the Bootstrap test, indicating that although enhancing the level of agricultural social services can promote technology diffusion, technology diffusion may not have an impact on agricultural carbon emissions. This conclusion is consistent with the study of Ma (Ma, 2006), who argued that agricultural technology diffusion not only includes low-carbon agricultural production technologies, but also technologies such as high concentration chemicals, heavy agricultural implements, and large water irrigation equipment, that would have an impact on carbon emissions, and the use of high concentration chemicals would still cause an increase in carbon emissions. In addition, although China establishes a large agricultural technology diffusion system, the efficiency of agricultural technology diffusion is limited by the differences in diffusion departments in different regions. Meanwhile, at present, China's agricultural social service system is not yet sound, and traditional services such as substitute plowing and purchasing occupy a large proportion, and although the level of agricultural mechanization has been improved, the traditional business behavior of farmers has not changed, which, together with the serious phenomena of capital shortage and aging knowledge, further restricts the diffusion of agricultural technology.

In summary, the transmission path of the agricultural scale effect is significantly present, while technology diffusion is not an efficient transmission path, that is, hypothesis 2 is valid, and hypothesis 3 is not.

5.4 Heterogeneity analysis

5.4.1 Distinguish between coastal provinces and inland provinces

Coastal and inland provinces differ in terms of agricultural development, production structure, labor force size, and adoption of

TABLE 9 Heterogeneity analysis.

Variables	Coastal provinces	Inland provinces	Eastern regions	Central regions	Western regions
	(a)	(b)	(c)	(d)	(e)
AS_{it}	−0.159 (0.209)	−0.588** (0.295)	−0.325 (0.218)	0.119 (0.250)	−2.586*** (0.307)
Control	YES	YES	YES	YES	YES
τ_t	YES	YES	YES	YES	YES
δ_i	YES	YES	YES	YES	YES
_cons	4.579*** (1.302)	3.535*** (0.702)	7.103*** (1.055)	9.188*** (1.771)	0.317 (0.791)
N	88	198	88	88	110
R-squared	0.969	0.846	0.962	0.854	0.951

Standard errors in parentheses.*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

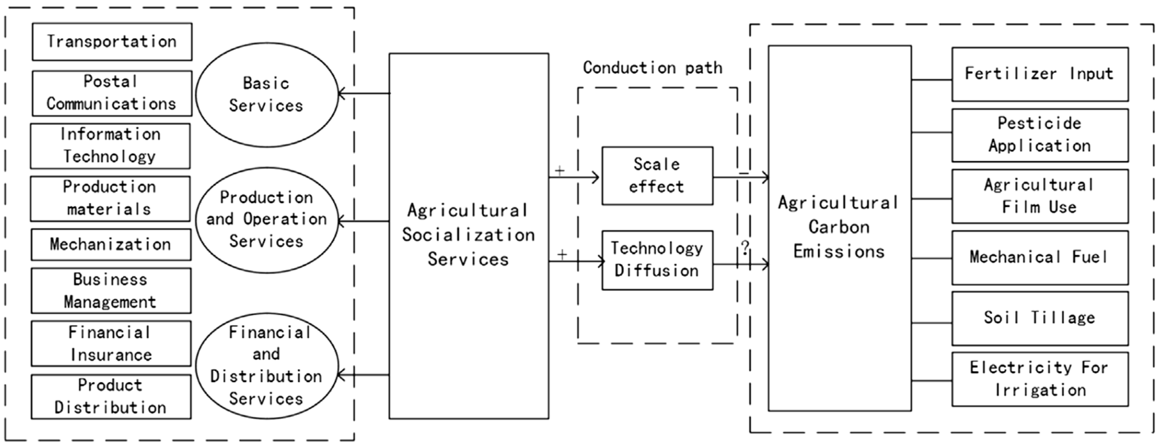

FIGURE 1
The transmission mechanism of the impact of socialized services on agricultural carbon emissions.

agricultural technologies, including low-carbon technologies. Therefore, the sample was divided into two sub-samples, coastal and inland provinces, and then regression analysis was conducted controlling for area fixed effects and time fixed effects, and the results are shown in models (a) and (b) in Table 9. The regression results show that socialized services can negatively affect the agricultural carbon emissions intensity in coastal and inland provinces, especially the effect is significant at the 1% level for inland provinces. However, there is no significant effect on agricultural carbon emissions intensity in coastal provinces, which may be due to the higher level of economic development in coastal areas and the weaker incentive effect of agricultural social services on agricultural operators. At the same time, under the national development strategy to ensure the security of food production, coastal areas to have a higher level of food output, agricultural operators will use modern agricultural production factors such as pesticides, fertilizers, and farm machinery frequently, which leads to an increase in carbon emissions and therefore does not show a significant carbon reduction effect.

5.4.2 Distinguish between eastern, central, and western regions

In terms of resource endowments, the eastern, central, and western regions have their regional heterogeneity. Therefore, the sample is divided into three sub-samples. Then, two-way fixed effects are controlled for and regression analysis is performed. As shown in models (c)–(e) in Table 9, in the east and west, agricultural socialized services have a negative impact on agricultural carbon emission intensity, especially in the west, the impact is significant at the level of 1%. For the central region, the effect of agricultural social services on agricultural carbon emissions intensity is not significant. The possible reason is that the eastern regions are mostly economically developed coastal cities, where agricultural

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operators have a deeper understanding of agricultural social services, and their operation scale and planting structure are more likely to be influenced by the promotion of socialized services, and their agricultural carbon emissions behavior will change. The western region has the natural advantage of having fewer people and more land, and the agricultural base in the western region is more backward, so if agricultural socialized services are promoted, it is easier to stimulate the willingness of agricultural operators to produce. The active participation of agricultural producers in the production of agricultural socialized services can reduce agricultural carbon emissions to a certain extent. Therefore, the carbon emissions reduction effect of socialized services is more reflected in the eastern and western regions, and the carbon emissions reduction effect in the central region is not obvious. Probably because the agricultural operators in the central region have a shallow understanding of socialized services, their carbon emissions behavior in production and operation is less influenced.

6 Conclusion and policy recommendations

Based on provincial panel data from 2010 to 2020 in China, we analyzed the effects of different types of socialized services on agricultural carbon emissions, and we further analyzed the possible ways for socialized agricultural services to reduce the intensity of agricultural carbon emissions with the help of mediating effect model. The results show that social services can provide basic services, production, and management services, financial services, and circulation services for the agricultural production chain, which can significantly reduce the agricultural carbon emission intensity. The results of the intermediation effect suggest that socialized services can break the labor constraint by promoting the scale effect, and thus reduce the agricultural carbon emission intensity. However, the mediation effect of technology diffusion is not significant. The reason is that although the diffusion of agricultural technology can improve the efficiency of resource utilization, the diffusion of technology also leads to the use of elements such as high concentrations of chemicals and heavy agricultural tools which may increase carbon emissions. In addition, the effect of social services on reducing agricultural carbon emission intensity shows obvious spatial heterogeneity, with the reduction gradually increasing from coastal to inland provinces and from eastern to western regions.

Based on the above conclusion, the following policy recommendations are proposed. 1) The government should actively promote the market-oriented construction of agricultural social services, support the development of relevant socialized service organizations, innovate the operation system of agricultural social services, and promote the specialization and standardization of agricultural production. While realizing large-scale operation, it promotes the green development of agriculture, reduces agricultural carbon emissions, and has a beneficial impact on the environment. 2) Actively innovate and develop environmentally friendly and low-carbon agricultural production technologies and promote them in scope, encouraging and guiding agricultural operators to adopt green and low-carbon technologies for production. Let the technology diffusion effect play more role in reducing agricultural carbon emissions through agricultural socialized services, promote the combination of technology and land, technology and species, technology and materials, and technology and services, and promote the innovation of agricultural formats. 3) In the eastern regions, central regions, and coastal cities, further increase the publicity related to socialized agricultural services to deepen agricultural operators' understanding and awareness of socialized services, so that the development of socialized agricultural services can boost large-scale agricultural operations and promote the low-carbon transformation of regional agriculture.

The recommendation for future research is that we need to pay more attention to agricultural social service policies, rural low carbon transition policies, and food growing policies. Analyzing the regional heterogeneity of the impact of food cultivation policies will lay the foundation for future agricultural green development.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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