frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 23 December 2022
DOI 10.3389/fenvs.2022.1032863

OPEN ACCESS

EDITED BY
Arshian Sharif,
Sunway University, Malaysia

REVIEWED BY
Edmund Udemba,
Gelişim Üniversitesi, Türkiye
Atif Jahanger,
Hainan University, China

*CORRESPONDENCE
Chuan Gu,
guchen0109@hunau.edu.cn

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management, a section of the journal Frontiers in Environmental Science

RECEIVED 31 August 2022
ACCEPTED 05 December 2022
PUBLISHED 23 December 2022

CITATION
Yi Y and Gu C (2022), Impact of structure and organization of smallholders on agricultural carbon emissions.
Front. Environ. Sci. 10:1032863.
doi: 10.3389/fenvs.2022.1032863

Impact of structure and organization of smallholders on agricultural carbon emissions

Yujie Yi and Chuan Gu*

School of Economics, Hunan Agricultural University, Changsha, China

Achieving carbon neutrality in agricultural production is a common challenge faced by agricultural development around the world. If China's agriculture sector intends to achieve the "dual carbon" goal, the focus should be on the agricultural carbon emission of smallholder farmers and their organized production. This study discusses the impact of smallholder structure and organized production on carbon emission, and the interaction mechanism. To describe the causal relationship and mechanism, the structural degree of smallholder farmers and the total carbon emission in the regions were measured, the provincial panel data were constructed, and then the fixed-effects model and intermediary mechanism test were used for empirical analysis. The results show that in the current stage of agricultural development, the high proportion of smallholders in the region will lead to more agricultural carbon emissions. Although organized production services can reduce carbon emissions, the structure of smallholders will inhibit the scale of the organization, thus hindering carbon emission reduction. It is stated that inhibition is the intermediary path for carbon emissions. This study suggests that the government should improve policies to guide smallholders to operate on an appropriate scale, strengthen policies to encourage smallholders to use socialized agricultural production services, and support smallholders in developing highly valuable ecological agriculture.

KEYWORDS
smallholder structure, organization production, agriculture carbon emission, intermediary mechanism, low carbon development

1 Introduction

Climate change has had adverse effects on agriculture over the last several decades. These effects are dependent on the degree to which agricultural production adapts to decrease the impact of climate change. This dependency is mostly heavy in developing countries where smallholder farmers are increasingly vulnerable to the effects of climate change because of the lack of essential adaptive capacity (Edmund, 2020). Consequently, it is of critical importance that possible adaptations are considered to avoid overestimating climate change's impacts on smallholder farmers' production. Owing to global climate change green and low-carbon development has become the consensus of development of all countries. In 2019, the EU issued the European Green Deal, which established the goal of "carbon neutrality" in Europe by 2050. After recommitting the United States to the Paris Agreement, the Biden administration proposed that the United States will achieve a net zero emissions target by 2050. The Chinese government also responsibly put forward the "dual carbon" goal, which strives to achieve a carbon peak by 2035 and carbon neutrality by 2050. In China, agriculture is the industry with the largest population and the widest range of regions, and the agriculture sector's carbon emissions account for approximately 18% of the total domestic carbon emissions. Therefore, it is of great importance to pay attention to the issue of carbon emission reduction in China's agriculture. To study this issue, it is vital to first recognize that the fundamentals of China's agricultural production are smallholder farmers (Chen 2019). In 2020, 85.1% of agricultural operators were smallholder farmers with less than 10 mu of arable land (Rural Social and Economic Investigation Department of the National Bureau of Statistics, 2020). Consequently, it is of great importance to focus on the structural characteristics of smallholder farmers. Therefore, this study attempts to explore the impacts and obstacles in the reduction of agricultural carbon emissions based on smallholder farmers.

What impact will smallholder production have on agricultural carbon emissions? The answer to this question is unclear. Traditionally, smallholder agricultural production has conducted intensive cultivation by increasing labor input and focusing on ecological and sustainable agriculture (Franklin, 2011) so that carbon emissions could be maintained at a low level. However, with the advancement of modern production, the rural labor force is reduced (Zhou et al., 2020; Lucy et al., 2022). Based on the comparison of income, smallholders will put more modern production factors into agricultural production. After chemical fertilizers, pesticides, and agricultural machinery are introduced into agricultural production (Fang et al., 2018; Huang, Forthcoming 2022), the overall agricultural carbon emissions will unavoidably increase. Therefore, it is necessary to investigate whether the impact of smallholder farmer production will inhibit or promote agricultural carbon emissions in the current situation. Furthermore, if the development of modern agriculture causes an increase in carbon emissions, how should we reduce carbon emissions based on the reality of smallholder agricultural production? There is a paradox here. From the practical experience of modern agricultural development in East Asia (Ma et al., 2018), it is possible to realize low-carbon production based on smallholders by organizing farmers through effective association and cooperation, using socialized production services, and scientifically reducing the use of modern production factors (Ishak et al., 2020; Sarkar et al., 2022). However, if there are many scattered smallholders in the region and there is an out-of-order production, this will undoubtedly increase the difficulty of organization coordination (Li et al., 2021), increase the management cost, and reduce the degree of organization, which is contrary to the goal of carbon reduction. In other words, smallholders are supposed to be organized to reduce carbon emissions. Still, too many smallholders will create difficulty in an organization and consequently will fail to achieve the carbon emission reduction target (Edmund, 2021). Therefore, it is necessary to further reform theories and point out the action path of reducing emissions by organizing smallholders.

The two aforementioned issues are the research challenges of this study. The mechanism of the impact of the organization when studying the impact of smallholder farmers and their organization on agricultural carbon emissions need to be investigated. This study collected data related to China's rural management in recent years, selected and calculated relevant indicators, established panel data, and analyzed the causal relationship through fixed effects. To answer the impact of smallholders organization, the paradox is tested by using the intermediary effect mechanism.

The objective of this study is to analyze the impact of smallholder farmer structure on organization and carbon emissions. The main contribution of this study is to discover that number of smallholder farmers who accounts for a high proportion of operating entities has led to an increase in carbon emissions from agricultural production. In particular, to find that forming the cooperation of smallholders in production links can effectively reduce the carbon emission level of agricultural production, the higher the proportion of smallholders in the region, the more difficult it is to organize production, and the scale level of cooperative production will decline, which is not conducive to carbon emission reduction. In addition, to verify that this smallholder farmer structure leads to difficulty in the organization, which will contribute almost 20% to the increase in carbon emissions.

The remaining manuscript is organized as follows. The second part is about the literature review. The third section describes the design scheme of the study. The fourth section illustrates the basic empirical data. The fifth part analyzes causal empirical and institutional tests. The sixth part summarizes the proposed research and proposes policy recommendations.

2 Literature review

The impact of smallholder agricultural production on carbon emissions and the path of organized emission reduction involve theoretical research on smallholder agricultural production, organization, and the degree of carbon emissions.

2.1 Relationship between smallholder production and agricultural carbon emission

There are disagreements about the environmental effects of the smallholder farmer production model. In the process of traditional agricultural model transformation, modern production factors are introduced into agricultural production (Schultz, 1987). Because of the promotion and use of agricultural technologies such as chemical fertilizers, the output is increased, which is conducive to the management of smallholder agriculture (Hazell and Ramasamy, 1991). There is a reverse relationship between the scale of agricultural land management and the yield of a single land. This is because, under the conditions of higher labor prices and lower capital prices, smallholders pursue higher output per unit area (Eastwood et al., 2010) and will choose to input relatively low-cost production factors, relying on chemical agricultural materials such as chemical fertilizers for production (Ali et al., 2020), increasing carbon emissions. At the same time, there is an opposite view that smallholder agricultural production should not have negative environmental effects. For example, Van Der Pleuger. (2016) believes that in the process of "re–smallholder farming," the smallholder farming model is based on the sustainable utilization of ecological capital, is a return to nature, and can realize the coordinated production between man and nature. Smallholder farmers' production is resilient (Duc et al., 2021) and can flexibly and autonomously adjust resource allocation. Some smallholder farmers follow the path of ecological agriculture (Liu et al., 2021).

The current smallholder agricultural production structure will lead to an increase in agricultural carbon emissions. Smallholder household management is a distinctive feature of China's agriculture for a long period the future. Under the pressure of the decline of the total area of cultivated land and the huge population size, the per-household cultivated land size of farmers is still declining (Huang and Ding, 2016). Traditionally, smallholder farmers prefer intensive cultivation to increase agricultural output. The land per unit yield efficiency of smallholders is much higher than that of large farmers (Bagi, 1982; Bizimana et al., 2004). Through "self-exploitation" to increase labor input to replace other factors (Chayanov, 1996), the carbon emission of agricultural production will not be high. However, with the development of China's market-oriented reform, a turbulent wave of marketization has swept through the countryside. Some strong workers in peasant households have moved to cities to work, and new factors of production have replaced them with agricultural production. In the new production environment, smallholders have difficulty using the old "on-the-ground" ecological resources, local experience, and knowledge to maintain production (Schultz, 1987). To improve sales income and reduce labor intensity, rational farmers will choose to invest in more modern factors in unit land to increase output and will use the "chemical agriculture" production method to generate more income. Thus, the smallholder agricultural production structure in China at this stage will lead to an increase in agricultural carbon emissions. Specifically, business activities, development, financial growth, and renewables are mitigating carbon emissions, while economic growth is increasing emissions (Edmund et al., 2022). Carbon emissions can be mitigated and better environmental quality achieved through the mechanisms of renewable energy, technological invention, FDI, and entrepreneurial activities (Edmund Ntom and Merve, 2022).

2.2 Effect of organized production on agricultural carbon emission

The impact of organized production on the environment is vague. The organizational development of farmers has helped farmers reduce transaction costs and increase agricultural income (Samanta et al., 1995; Sellare et al., 2020). Smallholders in China have entered the modern agricultural division of labor through professional farming (Zhang et al., 2017). Using the "vertical integration" socialized services provided by cooperatives and other organizations, they will have a higher probability of developing sustainable agriculture (Ma et al., 2017; Ma et al., 2021) and realizing the green transformation of agricultural production (Tang et al., 2018). However, there are also contrary empirical facts that show that under the goal of pursuing market returns, farmers' organized cooperative production will heighten the use of agricultural means of production such as fertilizers and pesticides (Abebaw and Haile, 2013; Blekking et al., 2021), thereby increasing carbon emissions in the production process.

Organized cooperative production is a realistic choice for agricultural carbon emission reduction (Edmund et al., 2022). Under the pressure of the dual carbon goal, what are the realistic and feasible options to ensure food production, ensure China's food security, and increase farmers' income? From the development process of developed regions in East Asia with similar natural endowment characteristics as China, the most reasonable way is to improve the level of smallholders' organization (Fernando et al., 2021). Although under the regulation of output and profit the way of organizational cooperation will increase the use of modern factors (Verhofstadt and Maertens, 2014), an organization can also promote the intensive use of sources of production and mitigate farmers' indifference and indiscriminate use. Regarding the use of sources of production, the organization has scale effects and technology spillover effects: it can conduct intensive production in an organized way, and reduce the excessive investment of individual farmers in agricultural materials as a whole. It can also promote soil testing formula fertilizer and biological pest control and other technologies, and scientifically and professionally apply means of production to reduce carbon emissions in agricultural production from two aspects. From the current agricultural production practice in China, the supply of socialized services to smallholders with the help of professional cooperatives, agricultural associations, and other business entities can help smallholders develop green and low-carbon production (Wang et al., 2018; Wu et al., 2018). Therefore, organized production is an effective way to reduce carbon emissions (Liu et al., 2021).

2.3 Influence of smallholder structure on organized production services

Smallholders need to adopt organized production services for the development of agricultural modernization in China. Organizing farmers to accomplish production cooperation is an effective measure to improve agricultural production efficiency (Narrow et al., 2009; Tefera et al., 2016; Lin et al., 2022). However, many organizational methods connecting smallholders have not achieved their goals (Markelova et al., 2009; Poulton et al., 2010). It is difficult to organize smallholders because of the farmers' scattered farmland and independent production. Empirical research shows that smallholder production inhibits the demand for agricultural production services and that large-scale farmers prefer to use organized social services (Qian et al., 2022).

However, an effective organization in smallholders is difficult to accomplish. In the process of organizing smallholder farmers, substantial human and financial resources should be invested to arrange the production. If there are a large number of scattered smallholder farmers in the region, it will increase the difficulty of organization coordination, increase the management cost, and inhibit the expansion of organizational scale, thus affecting carbon reduction. Therefore, in the process of organizing and connecting smallholders, there is a fact contrary to expectations: it was intended to reduce emissions by organizing smallholders, but it is difficult to form an effective organization because of too many smallholders.

2.4 Relationship path of mutual influence

From the analysis of the three aforementioned aspects, it can be surmised that smallholders and their organized production are the inevitable themes to achieve the dual carbon goal in agriculture. According to existing studies, on the one hand, the scale of modern factors invested by smallholders will be different at different levels of product development. In the accelerated development stage of agricultural modernization in China, the production structure of smallholders will cause carbon emissions. On the other hand, organized production will lead to changes in the input of modern factors of production. In addition to discussing the changes in the input of factors after farmers join the organization, this study not only focuses on the impact of the organization of production links on carbon emissions but also studies the impact of smallholder structure on the scale of the organization.

This article argues that there are two ways for smallholder farmers to increase agricultural carbon emissions: one is that smallholder farmers increase carbon emissions by increasing the use of modern production factors for subsistence and reproduction; the other is that intensive cultivation of smallholder farmers hinders the organization of cooperative management, which is not conducive to the reduction of carbon emissions. The relationship path is shown in Figure 1.

3 Methodology and data

3.1 Data sources

In this study, 31 provinces in mainland China were selected as the research samples. Because of extensive data loss in Tibet, this province was excluded from the analysis, and panel data from 30 provinces were constructed. Because the data published in the Statistical Annual Report of China's Rural Operation and Management and Statistical Yearbook of China's Rural Policy and Reform are from 2009 to 2020, relevant data from relevant years were collected in the samples. The data included in this study were retrieved from China Statistical Yearbook, China Rural Statistical Yearbook, China Rural Operation, and Management Statistical Yearbook, and China Rural Policy and Reform Statistical Yearbook.

3.2 Variable design and description

The main variables studied in this article are agricultural carbon emissions, smallholder structure, and agricultural organizational scale. To ensure reliable research results, a series of control variables were selected according to existing research conclusions.

3.2.1 Carbon emissions from agriculture

Considering that this research focuses on agricultural production, this study refers to the agricultural carbon emission measurement used by Li et al. (2011) and analyzes the six factors of a emission index including chemical fertilizers, pesticides, agricultural films, agricultural diesel, irrigation, and plowin, which are directly related to production. Among them, effective irrigation area and crop planting area were used as the indices of agricultural irrigation and plowing, respectively. The calculation method converts all types of inputs into carbon emissions and sums them up, as shown in Eq. 1, and the emission coefficient is shown in Table 1.

$$E = \sum_{i=1}^{6} E_i = \sum_{i=1}^{6} X_i \times \theta_i \tag{1}$$

In Equations 1, E is the total amount of carbon emissions of agricultural production, E_i is the carbon emission of six categories of carbon sources, X_i is the input amount of six

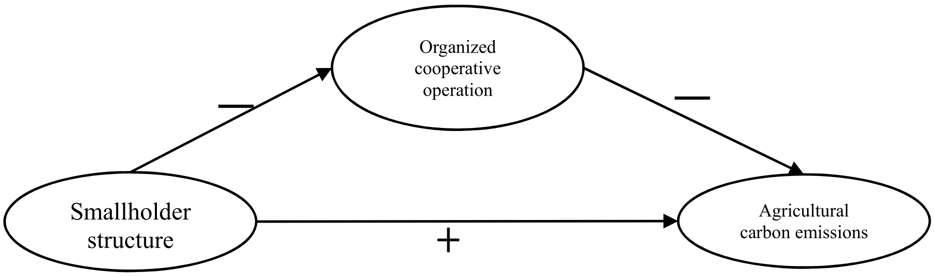

FIGURE 1
Carbon emission mechanism under smallholder agricultural production.

TABLE 1 Carbon emission sources of agricultural production, coefficients, and references.

Carbon emission sources of agricultural production	Carbon emission coefficient of agricultural production	References
Chemical fertilizer	0.8956 kg/kg	West et al. (2002)
Pesticides	4.9341 kg/kg	Oak Ridge National Laboratory (ORNL)
Agricultural plastic film	5.1800 kg/kg	Intergovernmental Panel on Climate Change (IPCC)
Agricultural diesel oil	0.5927 kg/kg	Nanjing Agricultural University's Institute of Resource, Ecosystem, and Environment of Agriculture
Crop planting area	312.600 kg/hm^2	Wu et al. (2007)
Agricultural irrigation area	20.475 kg/hm^2	Dubey et al. (2009)

categories of carbon emission sources, and θ is the carbon emission coefficient of various carbon emission sources.

3.2.2 Smallholder production structure

The farmers with less than 10 mu of arable land (excluding 10 mu) are defined as smallholder farmers in the Statistical Annual Report of China's Rural Operation and Management and Statistical Yearbook of China's Rural Policy and Reform. Given the great differences in population, regional area, and urbanization level of each province, if the absolute number of smallholder farmers in each province is used as an explanatory variable, it will be affected by the population in the region, and the overall structure of farmers in each region will be difficult to analyze. To better analyze the structural characteristics of farmers in the sample, the proportion of smallholder farmers in the total amount of all types of arable land was selected as the explanatory variable, and the calculation is shown in Eq. 2.

$$s\_farmer = \frac{z_1}{\sum_{i=1}^{6} z_i} \tag{2}$$

Eq. 2, s_farmer represents the proportion of smallholder farmers, z_1 represents the farmers with less than 10 mu of cultivated land, and z_i represents the six types of farmers with various cultivated land sizes classified in the Statistical Annual Report of Empirical Management in Rural China.

3.2.3 Organizational scale of agricultural production

Farmer-specialized cooperatives are the most important and fundamental attribute of the organization (Kong, 2021). It is an important way to develop modern agriculture under the national conditions of "big country, smallholders" to organize farmers *via* cooperatives and conduct large-scale production through socialized services. Although there are some problems in the current operation of cooperatives, such as low level, poor coverage, and insufficient connection, it is unquestionable that cooperatives organize smallholder farmers to produce and provide various trusteeship services, which is the mainstream mode of organized management of rural agriculture and a very applicable and desirable key carrier (Li and Ito, 2021). Moreover, cooperatives usually start with the combination of smallholder producers to purchase agricultural means of production (Chayanov, 1996). Therefore, this study selects "the total value of agricultural production inputs purchased by the unified organization" of professional cooperatives as the indicator of the scale of agricultural organizations.

TABLE 2 The statistical description of key variable indicators.

Variable name	Variable symbol	Mean value	Minimum value	Maximum	Standard deviation
Carbon emissions	carbon	281.969	11.481	861.290	193.200
Smallholder production	s_farmer	80.308	17.851	99.270	19.686
Organizational scale	org	75.559	0.004	445.821	90.360
Agricultural industrial structure	str	52.480	33.882	73.488	8.403
Urbanization level	urb	57.120	29.884	89.607	12.728
Financial input	fin	494.515	57.850	1,339.360	276.242
Disaster situation	dis	840.137	0	4,223.7	778.607

3.2.4 Control variables

As for the development level of the agricultural industry, it has been found that the development of the agricultural industry will affect agricultural carbon emissions (Raihan and Tuspekova, 2022). The leading agricultural industries of different provinces have different carbon emissions from different types of agricultural production activities (Kandadhar et al., 2021), so the proportion of the total agricultural output value of each region in the total output value of agriculture, forestry, animal husbandry, and fishery is used in the measurement. *Urbanization level*: urbanization will affect agricultural carbon emissions (Sufyanullah et al., 2022), which is expressed by the urbanization rate of the population in each region. *Financial support*: agricultural development benefits from the support of policies. This study chose local financial expenditure on agriculture, forestry, and water affairs to represent this variable. *Disaster situation*: agricultural production is strongly affected by the natural environment. The affected area of crops in each region was selected to express it.

The basic information on the variables involved in this study is shown in Table 2.

3.3 Measurement model and method

This study investigates the causal relationship between smallholder agricultural production and carbon emission. Therefore, agricultural carbon emission is taken as the explanatory variable, smallholder agricultural production as the explanatory variable, and other variables as the control variables. The benchmark model is shown in Eq. 3:

$$carbon_{i,t} = \beta_1 s\_farmer_{i,t} + \beta_2 pri_{i,t} + \beta_3 str_{i,t} + \beta_4 urb_{i,t} + \beta_5 fin_{i,t} + \beta_6 dis_{i,t} + \lambda_i + \gamma_t + u_{i,t} \tag{3}$$

Where i is the province, t is the year, λ_i is the individual effect, γ_t shows the time effect, β_0 is the constant term, β_i represents the parameters to be estimated of the six types of independent variables, and $u_{i,t}$ is the random interference term.

For the estimation method of panel data, fixed effects or random effects are selected for the model according to the results of the Hausman test. In addition, considering that there are significant differences in agricultural production in various regions of China, the agricultural policies and impacts of events in different periods are also different, so the individual effect and time effect will be fixed at the same time.

3.4 Intermediary effect test

To test whether organized scale has an intermediary effect between smallholder agricultural production and agricultural carbon emission, the intermediary effect test method proposed by Wen and Ye. (2014) is employed, which takes into account the probability of making the first and second types of errors. This test has a good testing effect and can easily measure the degree of intermediary effect. As a result, this study sets up the following three equations:

$$carbon_{i,t} = c \times s\_farmer_{i,t} + \theta_1 controls_{i,t} + \lambda_i + \gamma_t + \varepsilon_{i,t} \tag{4}$$

$$org_{i,t} = a \times s\_farmer_{i,t} + \theta_2 controls_{i,t} + \lambda_i + \gamma_t + \varepsilon_{i,t} \tag{5}$$

$$carbon_{i,t} = c' \times s\_farmer_{i,t} + b \times org_{i,t} + \theta_3 controls_{i,t} + \lambda_i + \gamma_t + \varepsilon_{i,t} \tag{6}$$

According to the five steps of the test procedure, the significance of regression coefficients c, a, b, and c' after the standardization of variables will be verified in turn. In addition, the indirect and direct effects and their proportion will be reported according to the similarities and differences between symbols ab and c. In the above equations, controls are various control variables set and $\varepsilon_{i,t}$ represent the random disturbance term of the model.

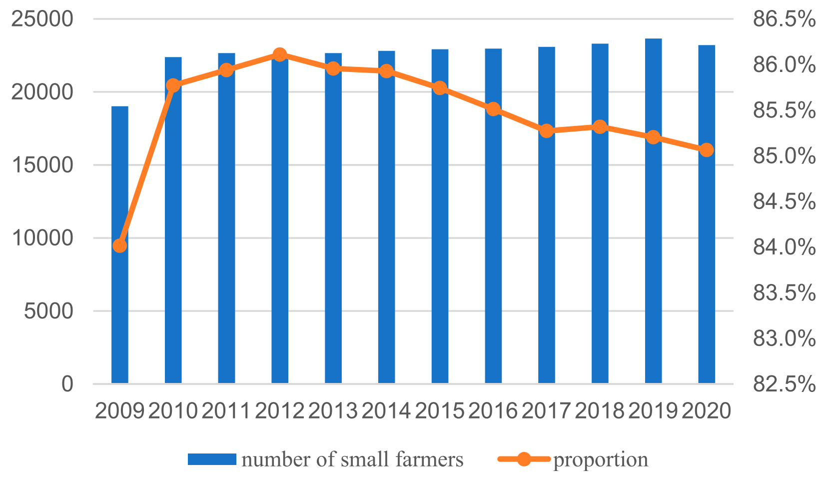

FIGURE 2
Changes in the number and proportion of smallholder farmers.

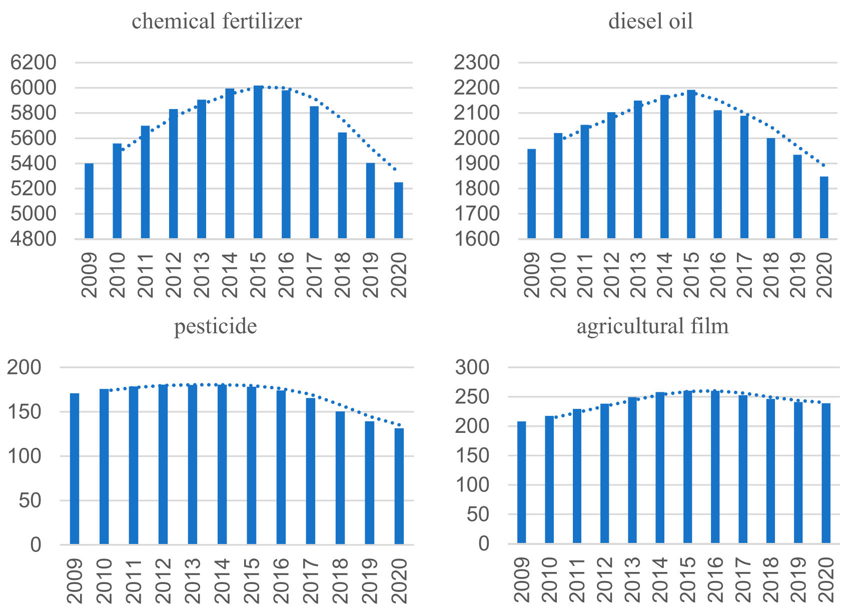

FIGURE 3
Input of four main means of agricultural production from 2009 to 2020.

4 Empirical facts

Smallholder farmers account for the largest number and proportion of all types of agricultural business entities. According to the statistics in the Statistical Annual Report of China's Rural Operation and Management and the Statistical Annual Report of China's Rural Policy and Reform. Figure 2, shows that in terms of quantity, smallholder farmers with less than 10 mu of arable land (excluding 10 mu) account for the largest number of business entities, with 190 million households in 2009 and 232 million households in 2020 respectively. The number has increased by 22.5% in the last 10 years. From the perspective of the main structure, smallholder farmers also account for the highest proportion. In 2009, the lowest proportion was 84.0%, and in 2012, the highest proportion was 86.1%. Since then, the proportion gradually decreased in the following 8 years (from 2012 to 2020), but the proportion was still greater than 85%. In 2020, the proportion was about 85.2%.

The input quantity of modern agricultural means of production showed a downward trend in the sample observation period. As shown in Figure 3, the data in the China Rural Statistical Yearbook (2009–2020) display that during this period, the input of the main means of modern agricultural production showed an inverted U shape. The application of chemical fertilizer, diesel oil, pesticide, and agricultural film reached its peak around the years 2014–2016 and then decreased year by year. By 2020, the four inputs were decreased by 12.75%, 15.69%, 27.46%, and 8.18%, respectively as compared with the peak value.

According to the empirical facts in Figure 2; Figure 3, the proportion of smallholder farmers shows a trend of first increasing and then decreasing before the input factors. Then, if the main sources of production are converted into carbon emissions, is there a causal relationship between smallholder farmers and agricultural carbon emissions? The further empirical analysis will be made subsequently.

5 Empirical analyses

The empirical analysis of this study is divided into three parts: the first includes analyzing the impact of smallholder agricultural production on agricultural carbon emissions, the second verifies the carbon reduction effect of organization, and the third examines the intermediary effect of cooperative organization production.

5.1 Impact of smallholder structure on agricultural carbon emissions

Before panel data are used, this study first tests the stationarity of all variable sequences. LLC test (Levin-Lin-Chu unit-root test), IPS test (Im-Pesaran-Shin unit-root test), and ADF test (Augmented Dickey-Fuller unit-root test) are used to investigate the stationarity of the variable series. The case with constant term and trend term is designed. It is found that under the 5% confidence interval, the horizontal variable of carbon emission cannot deny the original assumption that there is a unit root, showing that the horizontal variable is a non-stationary series. For this reason, the first-order difference processing is performed for all independent variables. After three types of stationarity tests were performed, it is found that all variables reject the original assumption that there is a unit root at the 1% level. This shows that all variables are in one order of integration.

After determining that the relevant variables are of the same order I (1) single integration, a panel cointegration test is performed to determine whether there is a common random trend among the variables. Because of the difference and time trend of the cointegration vector of the panel data, the Pedroni test (2004) and Westerlund test (2005) are used for the panel cointegration test, and the p values of both test results are less than $0.01 (p < 0.01)$. Therefore, the original assumption that "there is no cointegration relationship" can be rejected at the 1% level, which shows that there is a cointegration relationship.

The regression results of the panel data are shown in Table 3. Model one is the least-squares regression model controlling individual characteristics, model two is the fixed-effects model, model three is the random-effects model, and model four is the two-way fixed-effects model. In this study, the Hausman test is performed for models two and 3. The p-value of the test result is 0.000 ($p < 0.000$), which strongly rejects the original hypothesis. Therefore, it is considered that the fixed-effects model should be used instead of the random-effects model. Finally, the joint significance of all annual dummy variables is tested, and the results reject the original hypothesis of "no time-fixed effect", indicating that model four includes time-fixed effects.

From the results of each model, the proportion of smallholder farmers has a significant positive effect on carbon emissions. The higher the concentration of smallholder farmers, the higher the level of carbon emissions. The estimated coefficient of the proportion of smallholder farmers is significant at the 1% level in each model, indicating that the production structure of smallholder farmers has significantly increased the scale of agricultural carbon emissions. This reflects that smallholder farmers will invest in more modern agricultural means of production in agricultural production, increasing the level of carbon emissions of agricultural production.

Among all the control variables, the agricultural industrial structure has a major positive effect on the scale of agricultural carbon emissions. This confirms that the areas with a high proportion of planting production produce greater carbon emissions. Financial input also has a significant positive impact on carbon emissions. The reason is that policies support modern agricultural production and encourage more investment in modern agricultural means of production. Agricultural disasters have also significantly affected agricultural emissions. Perhaps in an area with frequent disasters, operators seek to ensure reliable output by investing in more agricultural materials.

5.2 Effect of organization on carbon emission from agricultural production

The organized scale has a very significant negative impact on the carbon emissions of agricultural production as shown in Table 4. The original assumption is rejected at the 1% level, indicating that the organized application of production inputs has a positive effect on reducing agricultural carbon emissions. Table 4 shows the results of the two-way fixed-effects model. The impact coefficient of the organization is −0.128 which shows that

TABLE 3 Estimated results of impacts of smallholder agricultural production on agricultural carbon emissions.

Carbon	m1	m2	m3	m4
s_farmer	2.575***	2.573***	2.026***	1.837***
	(4.397)	(4.305)	(3.639)	(3.285)
str		2.243***	2.299***	1.386**
		(3.714)	(3.710)	(2.438)
urb		−1.203*	−1.933***	−0.413
		(−1.899)	(−3.098)	(−0.530)
fin		0.011	0.030**	0.012
		(0.775)	(2.122)	(0.822)
dis		0.004	0.005	0.006**
		(1.176)	(1.574)	(2.101)
year				Yes
cons	229.534***	17.834	89.955	64.978
	(4.847)	(0.279)	(1.344)	(0.945)
N	360	360	360	360
R-Square	0.984	0.120		0.337
Adj. R-Square	0.98	0.03		0.24

Note: ***, **, and * respectively indicate significance at the 1%, 5%, and 10% levels, and the t values are in brackets, the same as in the succeeding tables.

an increase of 1 unit in the organization scale of agricultural production inputs will lead to a decrease of 0.128 units in agricultural carbon emissions.

5.3 Intermediary effect of organizational management

According to the step-by-step intermediary effect test method proposed by Wen and Ye. (2014), this study tests the intermediate effect of organized production. Table 5 reports the estimation results of the three models after variable standardization. Models m6, m7, and m8 correspond to Eq. 4 and 5, and Eq. 6, respectively. The first step is to test m6, and the estimated coefficient c is significant at the 1% level. The second step is to test coefficient an in m7 and coefficient b in m8. Both coefficients are significant at the 1% level, so the indirect effect is significant. The third step is to test the coefficient c' of m8, which is significant at the 1% level, representing that the direct effect is significant. The fourth step is to compare symbol abc' s. The two are the same sign, so there is some intermediary effect, and the proportion of intermediary effect in the total effect is 19.65%.

From the results of model 7, the proportion of smallholder farmers has a significant negative impact on the organizational scale. The coefficient after standardization is −0.605, and the

TABLE 4 Estimated results of the impact of the organization on agricultural carbon emissions.

Carbon	m5
org	−0.128***
	(−3.382)
str	0.782
	(1.337)
Urb	−0.063
	(−0.079)
fin	0.024
	(1.571)
dis	0.008***
	(2.684)
year	Yes
cons	150.922***
	(2.927)
N	221.427***
R-Square	(4.721)
Adj. R-Square	360

TABLE 5 Intermediate effect test of organization.

	m6	m7	m8
Variables	carbon	org	carbon
s_farme	0.187***	−0.605***	0.157***
	(3.285)	(−3.386)	(2.729)
org	--	--	−0.051***
	--	--	(−2.844)
pri	0.007**	−0.044***	0.005
	(2.438)	(−4.799)	(1.637)
str	−0.002	0.055***	0.001
	(−0.530)	(4.358)	(0.159)
urb	0.000	0.001***	0.000
	(0.822)	(4.329)	(1.482)
fin	0.000**	−0.000	0.000**
	(2.101)	(−0.114)	(2.106)
dis	0.007**	−0.044***	0.005
	(2.438)	(−4.799)	(1.637)
year	Yes	Yes	Yes
cons	−0.360	−1.288*	−0.425*
	(−1.473)	(−1.681)	(−1.751)
N	360	360	360
R-Square	0.337	0.457	0.354
Adj. R-Square	0.24	0.38	0.26

corresponding coefficient of non-standardization is −2.777 respectively, which is significant at the 1% level. The results show that the proportion of smallholder farmers in the region is high and the scale of cooperation of corresponding agricultural production organizations is also low. Moreover, the number of agricultural means of production purchased uniformly is also small.

From the regression results of model 8, the organizational scale is significantly negative at the 1% level. If the standardization coefficient is −0.051, then the non-standardization coefficient is −0.108. This result shows that organized production has a positive significance for reducing carbon emissions. Increasing the scale of farmers' professional cooperatives to organize farmers to purchase and use agricultural means of production can significantly reduce the level of agricultural carbon emissions. Meanwhile, the standardized coefficient of the proportion of smallholder farmers to carbon emissions is 0.157, and the non-standardized coefficient is 1.536, which is significant at the 1% level. The result shows that the regression coefficient of the proportion of smallholder and medium-sized farmers is still significant, but the influence coefficient is decreased.

According to the regression results and intermediate effects of models six to eight, the large percentage of smallholder farmers has both hampered the growth of organized production and increased carbon emissions. Moreover, this inhibition is also the impact path that smallholder farmers increase carbon emissions. In model 8, after the organizational scale variable is added, the impact coefficient of smallholder farmers' structure on carbon emissions is reduced by 0.03, indicating that the lack of organization caused by smallholder farmers' structure is partly responsible for the increase in carbon emissions. This intermediary effect path that inhibits the role of organized emission reduction accounts for 19.65% of the role of smallholder farmers' structure in increasing carbon emissions.

6 Conclusions and policy implications

6.1 Research conclusion

Agriculture development is critical to economic growth. However, it has both positive and negative effects on environmental quality. The negative effects have impacted the environment by damaging water, air, and health, as well as reducing natural resources. This article discusses the issue of reducing agricultural carbon emissions based on smallholder farmers and provides a theoretical analysis. According to the results, China's smallholder farmer structure will cause an increase in agricultural carbon emissions and the current agricultural modernization in China is a process of transforming traditional agriculture with modern elements proposed by Schultz. (1987), rather than a more natural ecological production process. Smallholders mostly use more modern means of production, which results in higher carbon emissions. Second, under the dual carbon goal, it is imperative to organize smallholders to carry out cooperative production. According to Verhofstadt and Maertens. (2014) organized production will cause agricultural environmental problems. However, this study states that scientific and appropriate uses of resource elements through an organization not only improve experience efficiency (Huang, 2018) but also reduce carbon emissions. Third, there is a paradox of smallholders' organization. Although smallholders need an organization to improve their business skills, it is large-scale holders that prefer adopting organized production and socialized services. As a consequence, the higher the proportion of smallholders in the region (Sufyanullah et al., 2022), the lower the level of organization, which offsets the role of the organization in carbon emission reduction and leads to the intermediary path of increasing carbon emissions. Renewable energy consumption and technological revolution ensure environmental quality, while economic and agricultural development has an impact on carbon emissions (Zhang et al., 2017). Ibrahim and Ajide. (2021) examined the effect of technology, trade, and agriculture on environmental quality in G-7 nations from 1991 to 2020. The findings discovered that technological advancement and renewable energy can reduce carbon emissions.

In general, the research results verify the mechanism path given in Figure 1, indicating that in the process of China's agricultural modernization, the high concentration of smallholders in the region will increase the carbon emission level of agricultural production. Although organized production can reduce the total amount of agricultural carbon emission, the structure of smallholders will inhibit the development of the organization, thus hindering agricultural carbon emission reduction.

6.2 Comparison with the past studies

Smallholder farming systems provide livelihoods and food for millions of households. Both policies and climate change are altering these systems (Campi et al., 2020). Presently, studies in the literature on the aspects influencing agricultural carbon emission focused mainly on the farmland management mode, economic growth, the growth of agricultural technology, and land use structure while studies on the organization of smallholders on agricultural carbon are relatively rare, especially in China (Rural Social and Economic Investigation Department of the National Bureau of Statistics, 2020). Studies about the impact of the former on agriculture carbon emission may not apply to China because agricultural specialization in China is not accompanied by a growth in farm size (Sufyanullah et al., 2022), whereas agricultural specialization and large-scale operations on farmland are frequently coupled in European and American countries (Huang, 2018). In addition, while prior research frequently examined how agricultural specialization affected agricultural factor inputs (fertilizers), biodiversity, and environmental sustainability (Kandadhar et al., 2021), only a small number of studies have explicitly outlined the connection between agricultural specialization, smallholders, and their impacts on agricultural carbon emission. Therefore this study on one hand analyzed the impact of smallholder farmer structure on organization and carbon emissions and discover that number of smallholder farmers accounts for a high proportion of operating entities has led to an increase in the carbon emissions of agricultural production. On the other hand, this study verified that smallholder farmer structure leads to an almost 20% increase in carbon emissions.

6.3 Policy enlightenment

This study asserts that when considering the dual carbon goal, the policy should make the following improvements according to the situation of smallholders. First, depending on modern technology, the transformation of smallholders' operations to develop high-value-added ecological agriculture should be supported (Udemba et al., 2022). Smallholders' production has the attribute of collaborative production with nature. In the process of agricultural transformation and upgrading through artificial intelligence and digitalization, the smallholders' natural production mode of planting and plant breeding needs to be reshaped. In the trend of the upgrading of residents' consumption, the consumption of agricultural products is not only for simple "satiety" but also a pursuit of satisfaction and health. Therefore, it is essential to make use of the advantages that the smallholders' production scenes are more in line with modern consumer demand, which enables smallholders through emerging digital technologies to produce high-quality green agricultural products on demand, to transmit the pastoral production landscape to consumers, to shorten the psychological distance between smallholder farmers and urban consumers, and to re-embed smallholder farmers in the social relationship with consumers. In the future, the mode of smallholder agricultural production will inevitably remain the fundamental aspect of China's agricultural operation. In the development of modern agricultural digital technology application demonstration projects, we should support high-tech methods to discover technologies that are suitable for smallholder agricultural production and help smallholders to make full use of natural resources to engage in agricultural production. Moreover, it is essential to ensure that ecological agricultural products are produced and are selling well, and integrate the green and low-carbon goal into the income of smallholders.

Second, policies that encourage smallholder farmers to use organized production services should be introduced. There is a shortage of rural labor force in China and the quality of the labor force is declining, and the labor force is generally a part-time process. The survey found that the average age of agricultural employees is 50 years, and the proportion of those older than 60 years is more than 24%. To maintain the stability of food production, more modern factors are bound to be used to replace the labor force in the process of smallholders' management (Fan et al., 2019), which increases the level of agricultural carbon emissions. Therefore, under the goals of food safety and dual carbon, it is crucial to encourage farmers to accept and adopt professional and large-scale productive services provided by service organizations. Consequently, the policies of governments at all levels to support agriculture should be reformed from subsidizing the main body, equipment, and technology to more energetically subsidizing the service. More funds should be used to support farmers' use of socialized services for agricultural production and to inspire smallholders to actively accept organizational services to achieve carbon emission reduction through the use of scale operation services.

Third, agricultural cooperative organizations should be controlled to provide production and operation services in accordance with green and low-carbon standards. The most suitable way to integrate smallholders into low-carbon agricultural production is to organize smallholder farmers to enter the professional planting and breeding link of socialized large-scale production, collect modern elements with the help of socialized services and cooperate in the use of green and low-carbon production services on a large scale with a low cost. However, some cooperative organizations simply pursue profits and output. Although they have increased agricultural output, they have diverged from the requirements of social green and low-carbon development, resulting in negative environmental impacts. Therefore, in agricultural productive service promotion, it is necessary to focus on the dual carbon goal, standardize the business behavior of cooperative organizations, strengthen the standard control of factor supply in production links, frame service indicators, and operation specifications, and develop a service quality and performance evaluation system.

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

YY: Conceptualization; Methodology; Formal analysis; Writing—original draft preparation. CG: Conceptualization; Methodology; Writing—review, and editing; Supervision.

Funding

This study was funded by the General program of the National Natural Science Foundation of China "agricultural land circulation promotes agricultural transformation and upgrading development: the intermediary role of agricultural TFP and the way out of 'three changes. Grant Number: 71973042.

Acknowledgments

The valuable comments and suggestions of editors and reviewers are gratefully acknowledged.

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.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abebaw, D., and Haile, M. G. (2013). The impact of cooperatives on agricultural technology adoption: Empirical evidence from Ethiopia. *Food Policy* 38, 82–91. doi:10.1016/j.foodpol.2012.10.003

Ali, B., Ullah, A., and Khan, D. (2020). Does the prevailing Indian agricultural ecosystem cause carbon dioxide emission? A consent towards risk reduction. *Environ. Sci. Pollut. Res.* 28 (4), 4691–4703. doi:10.1007/s11356-020-10848-3

Bagi, F. S. (1982). Relationship between farm size and technical efficiency in west Tennessee agriculture. *J. Agric. Appl. Econ.* 14 (02), 139–144. doi:10.1017/s0081305200024961

Bizimana, C., Nieuwoudt, W. L., and Ferrer, S. R. (2004). Farm size, land fragmentation and economic efficiency in southern Rwanda. *Agrekon* 43 (2), 244–262. doi:10.1080/03031853.2004.9523648

Blekking, J., Gatti, N., Waldman, K., Evans, T., and Baylis, K. (2021). The benefits and limitations of agricultural input cooperatives in Zambia. *World Dev.* 146, 105616. doi:10.1016/j.worlddev.2021.105616

Campi, M., Duenas, M., and Fagiolo, G. (2020). How do countries specialize in agricultural production? A complex network analysis of the global agricultural product space. *Environ. Res. Lett.* 15 (12), 124006. doi:10.1088/1748-9326/abc2f6

Chayanov, X. (1996). *Farmers' economic organizations*. Beijing: Central Compilation and Translation Press.

Chen, X. W. (2019). The context of rural revitalization strategy. *Ctry. Agric. Farmers (B)* 1, 18–22.

Dubey, A., and Lal, R. (2009). Carbon footprint and sustainability of agricultural production systems in Punjab, India, and Ohio, USA[J]. *Crop Improv.* 23 (4), 332–350. doi:10.1080/15427520902969906

Duc, K. N., Ancev, T., and Randall, A. (2021). Farmers' choices of climate-resilient strategies: Evidence from Vietnam. *J. Clean. Prod.* 317, 128399. doi:10.1016/j.jclepro.2021.128399

Eastwood, R., Lipton, M., and Newell, A. (2010). Chapter 65 farm size. *Handb. Agric. Econ.* 4 (9), 3323–3397. doi:10.1016/s1574-0072(09)04065-1

Edmund, N. (2021). Implication of energy expansion via the interaction of coal, industrialization, and agriculture towards climate goal: Dual sustainability analysis. *Environ. Sci. Pollut. Res.* 29, 25605–25622. doi:10.1007/s11356-021-17537-9

Edmund, N., Lucy, D., and Philip, F. E. (2022). Udemba (2022Performance and sustainability of environment under entrepreneurial activities, urbanization and renewable energy policies: A dual study of Malaysian climate goal. *Renew. Energy* 189, 734–743. doi:10.1016/j.renene.2022.03.024

Edmund, N. (2020). Mediation of foreign direct investment and agriculture towards ecological footprint: A shift from single perspective to a more inclusive perspective for India. *Environ. Sci. Pollut. Res.* 27, 26817–26834. doi:10.1007/s11356-020-09024-4

Edmund Ntom, U., and Merve, T. (2022). Energy transition and diversification: A pathway to achieve sustainable development goals (SDGs) in Brazil. *Energy* 239, 122199. doi:10.1016/j.energy.2021.122199

Fan, L., Dang, X., Tong, Y., and Li, R. (2019). Functions, motives and barriers of homestead vegetable production in rural areas in aging China. *J. Rural Stud* 67, 12–24. doi:10.1016/j.jrurstud.2019.02.007

Fang, J., Yu, G., Liu, L., Hu, S., and Chapin, F. S. (2018) Climate change, human impacts, and carbon sequestration in China. *Proc. Natl. Acad. Sci. U. S. A.* 115 (16), 4015–4020. doi:10.1073/pnas.1700304115

Fernando, S., Garnevska, E., Ramilan, T., and Shadbolt, N. (2021). Organisational attributes of cooperatives and farmer companies. *J. Co-op. Organ. Manag.* 9 (1), 100132. doi:10.1016/j.jcom.2021.100132

Franklin, R. (2011). *Four thousand-year-old farmers: Sustainable agriculture in China, korea, and Japan*. Beijing: Oriental Publishing House.

Hazell, P. B. R., and Ramasamy, C. (1991). *The green revolution reconsidered: The impact of high-yielding rice varieties in south India*. Delhi: Oxford University Press. doi:10.1016/j.jclepro.2020.123692

Huang, J. (Forthcoming 2022). China's rural transformation and policies: Past experience and future directions. *Engineering.* doi:10.1016/j.eng.2022.03.011

Huang, J., and Ding, J. (2016). Institutional innovation and policy support to facilitate small-scale farming transformation in China. *Agric. Econ.* 47 (1), 227–237. doi:10.1111/agec.12309

Huang, Z-Z. (2018). China's new age peasant economy: Reality and theory. *Open Times* 62 (03), 75+8–9.

Ibrahim, R. L., and Ajide, K. B. (2021). Nonrenewable and renewable energy consumption, trade openness, and environmental quality in G-7 countries: The conditional role of technological progress. *Environ. Sci. Pollut. Res.* 28, 1–18. doi:10.1007/s11356-021-13926-2

Ishak, S., Omar, A. R. C., Sum, S. M., Othman, A. S., and Jaafar, J. (2020). Smallholder agriculture cooperatives' performance: What is in the minds of management? *J. Co-op. Organ. Manag.* 8 (2), 100110. doi:10.1016/j.jcom.2020.100110

Kandahar, M. A., Udemba, E. N., Cheng, Y., Khan, Z. A., Koondhar, M. A., Batool, M., et al. (2021). Asymmetric causality among carbon emission from agriculture, energy consumption, fertilizer, and cereal food production-A nonlinear analysis for Pakistan. *Sustain. Energy Technol. Assessments* 45, 101099. doi:10.1016/j.seta.2021.101099

Kong, X-Z. (2021). *Realize the organic connection between smallholders and modern agricultural development*. Beijing: Economic Management Press.

Li, B., Zhang, J. B., and Li, H. P. (2011). Research on spatial-temporal characteristics and affecting factors decomposition of agricultural carbon emission in China. *China Popul. Resour. Environ.* 21 (08), 80–86. doi:10.3969/j.issn.1002-2104.2011.08.013

Li, M., Yan, X., Guo, Y., and Ji, H. (2021). Impact of risk awareness and agriculture cooperatives' service on farmers' safe production behaviour: Evidences from Shaanxi Province. *J. Clean. Prod.* 312, 127724. doi:10.1016/j.jclepro.2021.127724

Li, X., and Ito, J. (2021). An empirical study of land rental development in rural Gansu, China: The role of agricultural cooperatives and transaction costs. *Land Use Policy* 109, 105621. doi:10.1016/j.landusepol.2021.105621

Lin, B., Wang, X., Jin, S., Yang, W., and Li, H. (2022). Impacts of cooperative membership on rice productivity: Evidence from China. *World Dev.* 150, 105669. doi:10.1016/j.worlddev.2021.105669

Liu, D., Zhu, X., Wang, Y., Liu, Y., Ruiz-Menjivar, J., Zhang, L., et al. (2021). China's agricultural green total factor productivity based on carbon emission: An analysis of evolution trend and influencing factorsTechnical training and rice farmers' adoption of low-carbon management practices: The case of soil testing and formulated fertilization technologies in Hubei, China. *J. Clean. Prod.* 278226, 454–462. doi:10.1016/j.jclepro.2019.04.026

Lucy, D., Phili, F. E., and Edmund, N. (2022). Investigating possibility of achieving sustainable development goals through renewable energy, technological innovation, and entrepreneur: A study of global best practice policies. *Environ. Sci. Pollut. Res.* 29, 60302–60313. doi:10.1007/s11356-022-20099-z

Ma, W., Abdulai, A., and Goetz, R. (2017). Agricultural cooperatives and investment in organic soil amendments and chemical fertilizer in China. *Am. J. Agric. Econ.* 100 (2), 502–520. doi:10.1093/ajae/aax079

Ma, W., Renwick, A., Yuan, P., and Ratna, N. (2018). Agricultural cooperative membership and technical efficiency of apple farmers in China: An analysis accounting for selectivity bias. *Food Policy* 81, 122–132. doi:10.1016/j.foodpol.2018.10.009

Ma, W., Zheng, H., and Yuan, P. (2021). Impacts of cooperative membership on banana yield and risk exposure: Insights from China. *J. Agric. Econ.* 73 (2), 564–579. doi:10.1111/1477-9552.12465

Markelova, H., Meinzen-Dick, R., Hellin, J., and Dohrn, S. (2009). Collective action for smallholder market access. *Food Policy* 34 (1), 1–7. doi:10.1016/j.foodpol.2008.10.001

Narrow, C., Roy, D., Okello, J., Avendaño, B., Rich, K., and Thorat, A. (2009). Public-private partnerships and collective action in high-value fruit and vegetable supply chains. *Food Policy* 34 (1), 8–15. doi:10.1016/j.foodpol.2008.10.005

Poulton, C., Dorward, A., and Kydd, J. (2010). The future of small farms: New directions for services, institutions, and intermediation. *World Dev.* 38 (10), 1413–1428. doi:10.1016/j.worlddev.2009.06.009

Qian, L., Lu, H., Gao, Q., and Lu, H. (2022). Household-owned farm machinery vs. outsourced machinery services: The impact of agricultural mechanization on the land leasing behavior of relatively large-scale farmers in China. *Land Use Policy* 115, 106008. doi:10.1016/j.landusepol.2022.106008

Raihan, A., and Tuspekova, A. (2022). The nexus between economic growth, renewable energy use, agricultural land expansion, and carbon emissions: New insights from Peru. *Energy Nexus* 6, 100067. doi:10.1016/j.nexus.2022.100067

Rural Social and Economic Investigation Department of the National Bureau of Statistics (2020). *China Rural Statistical Yearbook*. Beijing: China Statistics Press.

Samanta, S. K., Hoff, K., Braverman, A. S., and Stiglitz, J. E. (1995). The economics of rural organization. *South. Econ. J.* 61 (3), 896. doi:10.2307/1061022

Sarkar, A., Wang, H., Rahman, A., Qian, L., and Memon, W. H. (2022). Evaluating the roles of the farmer's cooperative for fostering environmentally friendly production technologies-a case of kiwi-fruit farmers in Meixian, China. *J. Environ. Manag.* 301, 113858. doi:10.1016/j.jenvman.2021.113858

Schultz, T. W. (1987). *Transforming traditional agriculture*. Beijing: The Commercial Press.

Sellare, J., Meemken, E., Kouamé, C., and Qaim, M. (2020). Do sustainability standards benefit smallholder farmers also when accounting for cooperative effects? Evidence from côte d'Ivoire. *Am. J. Agric. Econ.* 102 (2), 681–695. doi:10.1002/ajae.12015

Sufyanullah, K., Ahmad, K. A., and Ali, M. A. S. (2022). Does emission of carbon dioxide impacted by urbanization? An empirical study of urbanization, energy consumption, economic growth, and carbon emissions - using ARDL bound testing approach. *Energy Policy* 164, 112908. doi:10.1016/j.enpol.2022.112908

Tang, L., Liu, Q., Yang, W., Wang, J., Xin, X., and Bai, J. (2018). Do agricultural services contribute to cost saving? Evidence from Chinese rice farmers. *China Agric. Econ. Rev.* 10 (2), 323–337. doi:10.1108/CAER-06-2016-0082

Tefera, D. A., Bijman, J., and Slingerland, M. (2016). Agricultural co-operatives in Ethiopia: Evolution, functions, and impact. *J. Int. Dev.* 29 (4), 431–453. doi:10.1002/jid.3240

Udemba, E. N., Firat, E., and Philip, L. D. (2022). Mitigating poor environmental quality with technology, renewable and entrepreneur policies: A symmetric and asymmetric approaches. *Renew. Energy* 189, 997–1006. doi:10.1016/j.renene.2022.03.060

Van Der Pleuger, J. D. (2016). *The new small peasant class*. Beijing: Social Science Literature Press.

Verhofstadt, E., and Maertens, M. (2014). Smallholder cooperatives and agricultural performance in Rwanda: Do organizational differences matter? *Agric. Econ.* 45 (S1), 39–52. doi:10.1111/agec.12128

Wang, Y., Zhu, Y., Zhang, S., and &Wang, Y. (2018). What could promote farmers to replace chemical fertilizers with organic fertilizers? *J. Clean. Prod.* 199, 882–890. doi:10.1016/j.jclepro.2018.07.222

Wen, Z-l., and Ye, B-j. (2014). Analyses of mediating effects: The development of methods and models. *Adv. Psychol. Sci.* 22 (05), 731–745. doi:10.3724/SP.J.1042.2014.00731

West, T. O., and Marland, G. (2002). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. *Agric. Ecosyst. Environ.* 91 (1–3), 217–232. doi:10.1016/s0167-8809(01)00233-x

Wu, F., Li, L., Zhang, H., and Fu, C. (2007). Net carbon emissions of farmland ecosystem influenced by conservation tillage [J]. *J. Ecol.* 26 (12), 2035–2039. doi:10.1000/4890.2007.12.2035.05

Wu, Y., Xi, X., Tang, X., Luo, D., Gu, B., Lam, S. K., et al. (2018). Policy distortions, farm size, and the overuse of agricultural chemicals in China. *Proc. Natl. Acad. Sci. U. S. A.* 15 (27), 7010–7015. doi:10.1073/pnas.1806645115

Zhang, X., Yang, J., and Thomas, R. (2017). Mechanization outsourcing clusters and division of labor in Chinese agriculture. *China Econ. Rev.* 43, 184–195. doi:10.1016/j.chieco.2017.01.012

Zhou, H., Yan, J., Lei, K., Wu, Y., and Sun, L. (2020). Labor migration and the decoupling of the crop-livestock system in a rural mountainous area: Evidence from Chongqing, China. *Land Use Policy* 99, 105088. doi:10.1016/j.landusepol.2020.105088