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# Research on the impact of fiscal environmental protection expenditure on agricultural carbon emissions

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China's agricultural and rural greenhouse gas emissions account for about 15% of its total emissions. Studying how to reduce China's agricultural carbon emissions (ACEs) is of great strategic significance. Based on the panel data of 31 provinces (cities) in China from 2007 to 2020, this paper empirically tests the impact of fiscal environmental protection expenditure (FEPE) on ACEs. The results reveal that: FEPE has significant negative impacts on ACEs; FEPE has a heterogeneous impact on ACEs in different regions, which shows that it has a significant impact on the eastern and central regions and provinces with relatively "high" carbon emissions, while it has no significant impact on the western regions and provinces with relatively "low" carbon emissions; Further the results of mechanism analysis show that the impact of FEPE on ACEs is mainly manifested in its inhibiting effect on agricultural diesel, fertilizer and film use of carbon emissions. In light of these findings, it is imperative for the government to ensure steady and substantial investments in environmental protection. Moreover, implementing region-specific measures is essential to effectively curbing ACEs. The findings of this study offer invaluable insights that can guide the formulation of policies aimed at effectively reducing ACEs.

KEYWORDS

**fiscal environmental protection expenditure, agricultural carbon emissions, policy research, China, greenhouse effect**

## 1 Introduction

Over an extended period, the excessive depletion of agricultural resources has led to a notable rise in agricultural non-point source pollution. This escalation in pollution has triggered a warning signal for the ecological environment, signifying a critical state (Abbas et al., 2022a; Elahi et al., 2022a; Abbas et al., 2022b). Consequently, this situation is closely associated with the occurrence of extreme weather events (Elahi et al., 2022b). Relevant evidence shows that the total emissions of agricultural greenhouse gases account for about 25% of the global emissions, which have exceeded the carbon emissions of the transport industry, and even close to the carbon emissions of electricity production. As an open ecosystem, the agricultural system needs a lot of auxiliary inputs such as fertilizer and agricultural machinery from the outside to continuously promote the smooth flow of energy, material and information and maximize the economic value flow. These inputs are becoming a source of ACEs and contributing to global warming and greenhouse effect. As a large agricultural country, China's agricultural and rural greenhouse gas emissions account for about 15% of its total emissions. Therefore, studying whether FEPE can reduce ACEs, whether there are any heterogenous impacts among different regions and how FEPE affects ACEs are of great strategic significance. We gathered panel data at the provincial level in China and used the ordinary least squares methods to examine the impacts of FEPE on ACEs.

Our paper is mainly related to three branches of research: firstly, the research on the intensity and efficiency of agricultural carbon emissions. Carbon emissions from agricultural production account for nearly 15% of the total human carbon emissions (Laborde et al., 2021). ACEs accounted for 20% of the global total carbon emissions in 2017 (Zhang et al., 2019a), with 17% of total carbon emissions for China (Guan et al., 2008). As the largest agricultural country in the world, China's ACEs account for 11%–12% of the world's total (Guo et al., 2022) and are about twice those of the United States (Bai et al., 2019). How to measure ACEs is also a topic that scholars have been paying attention to. West and Marland (2002) divided ACEs into fertilizer, pesticide, irrigation and seed cultivation. Johnson, et al. (Johnson et al., 2007) also divided ACEs into four categories. In contrast, Mosier et al. (1998) divides ACEs into land use, plant growth and animal breeding. Certainly, these definitions are quite close with slight differences. And Liu, et al. (Liu et al., 2021a) found ACEs in China showed an inverted-"U" trend, with the overall growth rate declining gradually. Li and Wang (2023) also demonstrated that China's ACEs started to fall after 2015.

Secondly, our research is also relevant to the influencing factors of agricultural carbon emissions. Northrup et al. (2021) believed that advances in agricultural technology could reduce agricultural carbon emissions. Zhao et al. (2018) found that water resource utilization efficiency has a greater impact on reducing ACEs, and Hinz et al. (2020) demonstrated that agricultural production efficiency can significantly reduce ACEs. Some scholars have also found that compared with the situation in 1975, the ACEs have decreased by more than one-half due to the reduced agriculture areas (Ali and Nitivattananon, 2012). Also scholars found that land use change can lead to great decrease in fertilizer and pesticide use (Ren et al., 2019; Haider et al., 2020). Holka et al. (2022) demonstrated that the mineral fertilizer is the main source of the ACEs, and organic farming has the potential for reducing ACEs. Yang, et al. (Yang et al., 2022a) discovered that quality improvement projects can reduce ACEs. Scholars also found agricultural management practices can also reduce ACEs (Yu et al., 2013; Peter et al., 2017).

However, the role of agricultural technology progress in agricultural carbon emissions is uncertain. Under the background of smallholder farming, it is assumed that agricultural environmental pollution can be reduced through moderately expanding the farm size, but it is not suitable for agricultural carbon emissions (Wang et al., 2022). In recent years, scholars have also begun to pay attention to the impact of green credit policies on agricultural carbon emissions. For example: Qin et al. (2023) have studied the inhibition effect of green credit on agricultural carbon emissions. Guo, Zhao, Song, Tang and Li (Guo et al., 2022) found that, fertilizer consumption and ACEs have a positive correlation, but green finance can significantly reduce ACEs. In essence, green credit policy is also an environmental regulation policy. Furthermore, we try to examine the impact of FEPE (as one kind of environmental regulation policy) on ACEs, which is innovative.

Thirdly, our research also tries to explore the impact of FEPE (short for fiscal environmental protection expenditure) on the ecological environment, which is controversial. Most scholars support the positive role of fiscal expenditure. For example, López et al. (2011) had proved the positive effect of public expenditure on air quality and water quality. He et al. (2018) noted that FEPE in China was not conducive to air quality. Xie et al. (2021) found that increasing financial expenditure in China did help improve energy and carbon emission efficiency. Huang (2018) found a negative link between FEPE and SO2 emission in China. Xu et al. (2023) also confirmed the relation between FEPE and CO2, but found the expenditure efficiency stayed at a relatively low level. However, Moshiri and Daneshmand (2020) found that FEPE had no significant impacts on environmental protection in Iran. Adewuyi (2016) believed that the government expenditure can show the opposite effect in the short term and long term. Galinato and Galinato (2016) showed that fiscal expenditure increases forest land clearing for agricultural production, which leads to more carbon dioxide emissions. Therefore, the impacts of FEPE on ACEs are still worth empirical testing. Moreover, we examine the heterogeneous impacts of FEPE on agricultural carbon emissions, which can enable us to have a deeper understanding of the applicability of FEPE policies in different regions; Although lots of scholars have confirmed the effect of FEPE on environmental pollution, the mechanism how FEPE affected ACEs have not been explored yet, which is also our research topic.

## 2 Theoretical analysis

Known as the Porter Hypothesis (PH), the proposition that appropriate environmental regulation will stimulate technological innovation was proposed by Porter (1991); Porter and Vanderlinde (1995). Lots of scholars have demonstrated that environmental regulation can promote innovative behavior of enterprises (Ambec and Barla, 2002; Hamamoto, 2006; Yang et al., 2012; Rubashkina et al., 2015).With the concept of green development, Chinese governments have continuously increased financial investment in energy conservation and emission reduction, greatly promoting the green development. The data from the National Bureau of Statistics reveal that the expenditure on energy conservation and environmental protection showed a steady and rapid growth trend from 2007 to 2020. In 2019, it reached the maximum of 739.02 billion yuan, accounting for 3.09% of the national public expenditure in that year.

As an environmental regulation policy, FEPE can reduce carbon emissions from two aspects: The first is regulation and prevention of pollution sources. Fan et al. (2020); Halkos and Paizanos (2013) demonstrated that FEPE can effectively promote energy conservation and reduce carbon emissions. The second is the treatment of discharged pollutants. Chinese government has established natural forest protection and pollution reduction accounts under the FEPE account. The pollution reduction account is used to measure the funds spent on various types of pollutant treatment, including pollution reduction facilities, emission reduction technologies, R&D investment, and emission reduction costs. Government can improve environmental quality by punishing environmental pollution behavior (Raza, 2020; Zhang et al., 2022). Of course, as a fiscal expenditure item, the increase in FEPE may also indirectly affect carbon emissions by affecting economic development. Due to the non-linear relationship between economic development and carbon emissions, this indirect effect is uncertain. But according to Fan, Li, Wang and Li (Fan et al., 2020), the direct effect of FEPE will outweigh the indirect effect, which will have an inhibitory effect on carbon emissions. Therefore, this paper proposes:

**Hypothesis 1.** FEPE can reduce ACEs.

The impact mechanism of FEPE on ACEs is through two pathways. The first is to reduce ACEs through the agricultural non-point source pollution. In China, chemical oxygen demand emissions in agricultural pollution exceed the industrial sector and become the main source of chemical oxygen demand emissions (Chen et al., 2021). And agricultural non-point source pollution has always been the most important factor affecting agricultural carbon emissions (Zhang et al., 2019b; Zou et al., 2020). The long-term irrational use of agricultural chemical inputs such as fertilizers, pesticides and agricultural films has made agricultural non-point source pollution more serious, aggravated soil pollution on cultivated land, and thus affected ACEs.

The second aspect of our research focuses on enhancing agricultural productivity. Through advancements in agricultural technology, particularly the widespread adoption of agricultural mechanization, we can not only elevate the efficiency of agricultural production but also facilitate the optimal utilization of agricultural infrastructure, fertilizers, pesticides, agricultural film, and other material resources. This, in turn, contributes to a reduction in agricultural carbon emissions. Studies have confirmed that a bundle of AGPTs (agricultural green production technology) are applied to maximize total yield and products quality, such as weed and pest control, soil and water conservation technology. Abdulai and Huffman (2014) argued that the adoption of this technology increases rice yields and net returns significantly. Besides, Midingoyi, et al. (Midingoyi et al., 2018) found that farmers who adopt integrated pest management have higher mango yields, and also use lower quantities of insecticide and cause less damage to the environment.

From the perspective of causality, both agricultural technology progress and agricultural non-point source pollution (fertilizer, pesticide, agricultural film) emerge as pivotal factors that can either contribute to the escalation or mitigation of agricultural carbon emissions. However, existing research has not definitively established the dominant mechanism in this regard. Building upon these considerations, this paper proposes:

**Hypothesis 2.** FEPE will inhibit ACEs by reducing agricultural non-point source pollution (fertilizer, pesticide, agricultural film).

**Hypothesis 3.** FEPE will inhibit ACEs by improving agricultural technology progress.

# 3 Models, variables and data sources

## 3.1 Model design

This paper mainly formulates the following econometric models:

$$C_{it} = \beta_0 + \beta_1 \times FEPE_{it} + \sum_{k=1}^{n} \beta_k \times Control_{kit} + \mu_i + \lambda_t + \nu_{it} \quad (1)$$

Among (1), $C_{it}$ represents agricultural carbon emissions, $Fin_{it}$ means FEPE, and we are concerned about the coefficient in front of the variable FEPE, and if $\beta_1$ is significantly negative, it means that FEPE can significantly reduce agricultural carbon emissions. $Control_{kit}$ represents other control variables. Additionally, we incorporate individual fixed effect and time fixed effect to exclude the influence of unchanging individual characteristics and temporal trends.

**TABLE 1** The source, coefficient and reference of ACEs.

| Source | Coefficient | References |
|---|---|---|
| fertilizer application | 0.8956 | West and Marland, (2002) |
| pesticide input | 4.934 | Li et al., (2011) |
| agricultural film utilization | 5.18 | Li et al., (2011) |
| diesel consumption | 0.5927 | IPCC, (2007) |
| tillage | 312.6kg/km2 | Wu et al., (2007) |
| irrigation | 20.476 kg/ha | Dubey and Lal, (2009) |

## 3.2 Variable description

### 3.2.1 Dependent variable

ACEs are the carbon emissions generated by the input of factors in the production process of planting industry in a relatively narrow sense. Referring to the relevant literature (Zhang et al., 2019a), the sources of ACEs are mainly defined in the six aspects of fertilizer application, pesticide input, agricultural film utilization, diesel consumption, tillage and irrigation in the agricultural production process. The corresponding coefficients are 0.8956, 4.934, 5.18, 0.5927, 312.6kg/km2 and 20.476 kg/ha, respectively, which is shown in Table 1. Then we can calculate agricultural carbon emissions according to formula (2). We collect the data of fertilizer application, pesticide input, agricultural film utilization and diesel consumption from China's rural statistical yearbook. Tillage and irrigation are respectively expressed by the actual planting area and irrigation area of crops in China.

$$C_t = \sum_{k=1}^{k} c_{kt} = \sum_{k=1}^{k} \delta_k \omega_k \quad (2)$$

Among (2), $C_t$ represents the total ACEs of each province; k and t represent the type and year of carbon emission sources respectively; $c_{kt}$ represents the carbon emissions from all kinds of sources; $\delta_k$ and $\omega_k$ represents the carbon emission coefficient and corresponding element input from all kinds of sources.

### 3.2.2 Core explanatory variables

FEPE is measured by the proportion of the fiscal expenditure on energy conservation and environmental protection in the total fiscal expenditure. In 2006, China officially established the subject of expenditure on environmental protection in the

**TABLE 2** Variables and data sources.

| Variable | Calculation formula | Data sources |
|---|---|---|
| ACEs | The calculation formula is shown in Eq. 2 | China Rural Statistical Yearbook |
| FEPE | Proportion of financial energy conservation and environmental protection expenditure in total financial expenditure | Provincial Statistical Yearbook |
| Agricultural mechanization | The ratio of total mechanical power to the number of employees in the primary industry | China Rural Statistical Yearbook |
| Multiple crop index | Proportion of total sown area of crops to cultivated area | Provincial Statistical Yearbook |
| Scale management of agricultural land | The ratio of total sown area of crops to the number of employees in the primary industry | |
| Planting structure | Proportion of grain sown area to total crop sown area | |
| Urbanization level | Proportion of urban permanent population to total permanent population | |
| Consumption level of rural residents | Per capita consumption expenditure of rural residents | |

classification of budget expenditure. In 2007, the "environmental protection" category of expenditure was set up in the general public budget expenditure, which is uniformly used for the expenditure of funds related to environmental protection. In 2011, the "Environmental protection" subject was renamed "Energy Conservation and Environmental Protection" subject. Therefore, the ratio of fiscal expenditure on energy conservation and environmental protection to total fiscal expenditure can be used to reflect the importance of the government to energy conservation and environmental protection (Fan et al., 2022; Sheng et al., 2022).

### 3.2.3 Control variables

Referring to the research of Raihan and Tuspekova (2022); Bashir et al. (2023); Li et al. (2023), and considering the data availability, we select the following six control variables.

- *Agricultural mechanization,* which is measured by the ratio of total mechanical power to the number of employees in the primary industry to control the impact of agricultural labor input on agricultural carbon emissions.
- *Multiple cropping index.* It is characterized by the ratio of the total planting area of crops to the cultivated land area, which has effects on ACEs by affecting the scale of agricultural planting.
- *Scale management of agricultural land,* which affects the agricultural planting scale, is measured by the ratio of the total planting area of crops to the number of employees in the primary industry.
- *Planting structure,* which is measured by the ratio of grain sown area to total crop sown area so as to reflect the "grain-oriented" characteristics of planting structure.
- *Urbanization level is* characterized by the ratio of urban population to regional permanent population.
- *Consumption level of rural residents* have an impact on ACEs by influencing the scale of agricultural planting and other aspects, which is measured by the *per capita* consumption expenditure of rural residents.

## 3.3 Data sources

As China designated environmental protection as a fiscal expenditure category in 2007, this article mainly collected panel data of 31 provinces (cities) in mainland of China from 2007 to 2020. The original data pertaining to fertilizer application, pesticide input, agricultural film utilization, diesel consumption and agricultural mechanization are sourced from China's rural statistical yearbook. Other relevant original data including financial energy conservation and environmental protection expenditure, total financial expenditure, total power of agricultural machinery, number of employees in the primary industry, *per capita* consumption level of rural residents, grain planting area, crop planting area, cultivated land area, urbanization level, etc. are extracted from China's statistical yearbook. Detailed sources are provided in Table 2. Any instances of missing data were supplemented using the moving average method. Descriptive statistical outcomes are presented in Table 3.

## 3.4 The spatiotemporal evolution characteristics of agricultural carbon emissions in China

Using the natural breakpoint classification method, China's agricultural carbon emissions are categorized into five distinct levels and visually represented on a map, as depicted in Figure 1.

From Figure 1, several conclusions can be drawn: firstly, prior to 2014, ACEs in various regions of China showed an upward trend. However, in recent years, these emissions in different regions of China have exhibited a consistent downward trend; notable and persistent disparities in agricultural carbon emissions are evident among China's diverse regions. Substantial differences exist between major agricultural provinces and non-agricultural provinces, as well as between the eastern, central, and western regions. Thirdly, ACEs in prominent agricultural provinces such as Henan, Shanxi, and Heilongjiang are positioned at a high level, while emissions in regions such as Fujian, Zhejiang, and Tibet remain at a lower level.

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**TABLE 3** Descriptive statistical results of main variables.

| Variable | Number of samples | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|---|
| ACEs | 434 | 5.361 | 1.108 | 2.293 | 6.903 |
| FEPE | 434 | 0.030 | 0.011 | 0.008 | 0.068 |
| Agricultural mechanization | 434 | 4.150 | 2.069 | 0.864 | 12.59 |
| Planting structure | 434 | 0.655 | 0.135 | 0.328 | 0.971 |
| Scale management of agricultural land | 434 | 6.834 | 3.559 | 2.090 | 27.71 |
| Urbanization level | 434 | 1.289 | 0.376 | 0.488 | 2.324 |
| Multiple crop index | 434 | 55.34 | 14.27 | 21.50 | 93.77 |
| Consumption level of rural residents | 434 | 8,460 | 4,232 | 2080 | 22,449 |

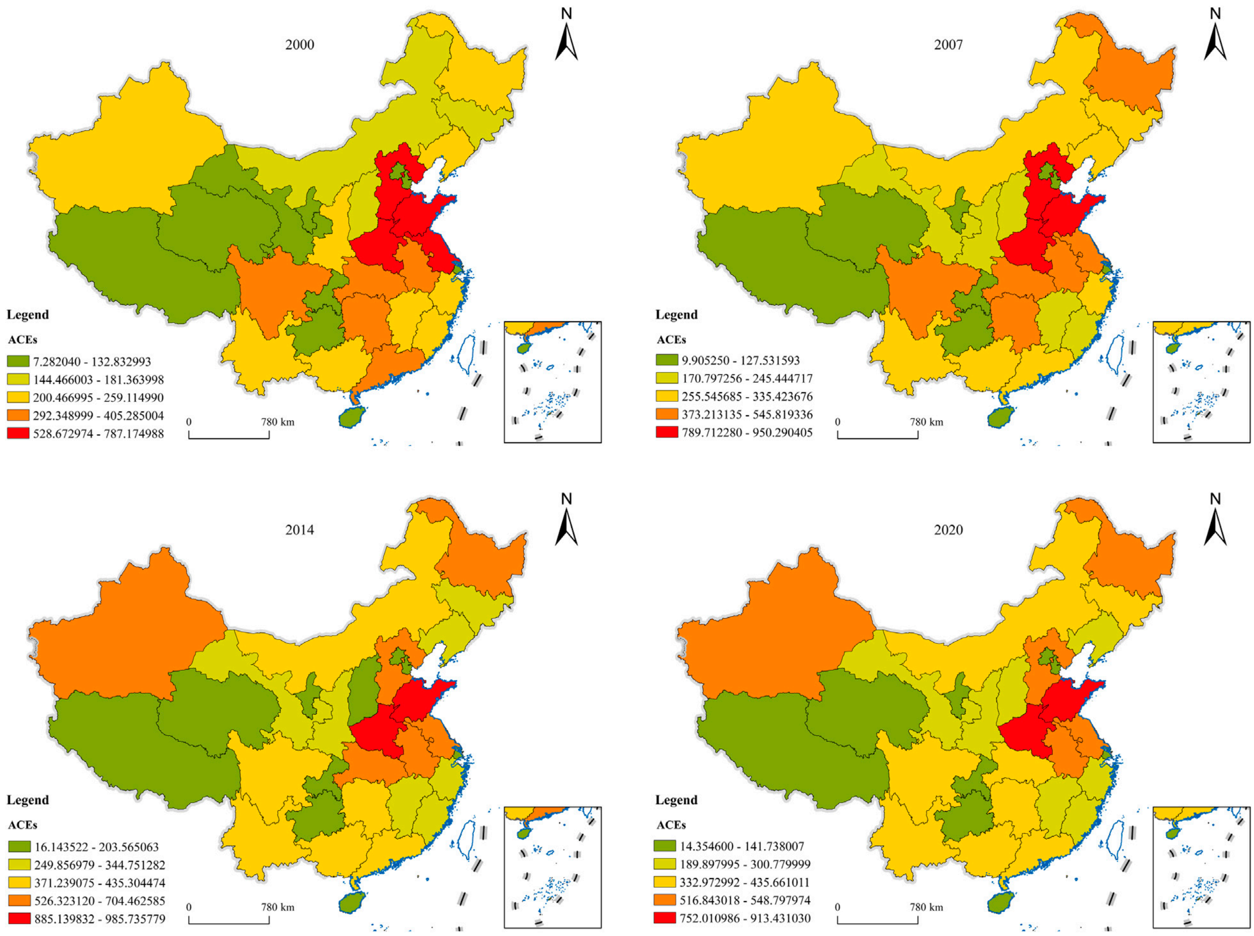


FIGURE 1
The spatiotemporal evolution trend of ACEs in various regions of China.

# 4 Results

## 4.1 Benchmark regression analysis

Prior to conducting the regression analysis, a Pearson correlation analysis was performed on the primary variables to mitigate the potential issue of severe multicollinearity. The outcomes of this analysis are presented in Table 4.

Table 3 indicates noteworthy correlations between ACEs and several variables. ACEs display a significant negative correlation with variables like FEPE, Urbanization level, and Consumption level of rural residents. Conversely, ACEs exhibit a significant

TABLE 4 Correlation coefficient of main variables.

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| (1) ACEs | 1 | | | | | | | |
| (2) FEPE | −0.105* | 1 | | | | | | |
| (3) Agricultural mechanization | 0.036 | 0.055 | 1 | | | | | |
| (4) Planting structure | 0.216* | 0.285* | 0.400* | 1 | | | | |
| (5) Scale management of agricultural land | 0.251* | 0.116* | 0.586* | 0.405* | 1 | | | |
| (6) Urbanization level | 0.271* | −0.350* | −0.118* | −0.334* | −0.151* | 1 | | |
| (7) Multiple crop index | −0.218* | −0.102* | 0.222* | −0.034 | 0.243* | 0.098* | 1 | |
| (8) Consumption level of rural residents | −0.111* | −0.048 | 0.344* | −0.149* | 0.222* | 0.183* | 0.717* | 1 |

Note: * indicates significant at 5% level.

TABLE 5 The impact of FEPE on ACEs.

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| FEPE | −7.18*** | −4.74*** | −5.30*** | −4.20*** |
| | (−11.86) | (−8.20) | (−8.68) | (−7.87) |
| Agricultural mechanization | | 0.04*** | | |
| | | (9.13) | | |
| Planting structure | | −0.28** | −0.25** | −0.21** |
| | | (−2.45) | (−2.11) | (−2.01) |
| Multiple crop index | | 0.04 | 0.04 | 0.04 |
| | | (1.20) | (1.12) | (1.31) |
| Urbanization level | | 0.01*** | 0.01*** | |
| | | (5.45) | (4.28) | |
| Scale management of agricultural land | | | 0.02*** | 0.02*** |
| | | | (5.37) | (5.06) |
| Consumption level of rural residents | | | | −0.00*** |
| | | | | (-11.80) |
| Year Fixed Effect | Yes | Yes | Yes | Yes |
| Province Fixed Effect | Yes | Yes | Yes | Yes |
| *N* | 434 | 434 | 434 | 434 |
| adj. $R^2$ | 0.994 | 0.996 | 0.995 | 0.996 |

Note: The values in brackets are t statistics, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

positive correlation with variables such as Planting structure and Agricultural land scale management. Additionally, ACEs show a significant positive correlation with the Multiple cropping index while having no significant correlation with Agricultural mechanization. Notably, a robust correlation exists between Urbanization level and Consumption level of rural residents, evidenced by a correlation coefficient of 0.717. Similarly, a strong correlation of 0.586 emerges between Agricultural mechanization and Scale management of agricultural land. This highlights the necessity of excluding these highly correlated variables from the model simultaneously to avert severe multicollinearity, which could compromise the stability of regression coefficients. As a solution, we adopt stepwise regression analysis to scrutinize the impact of FEPE on ACEs. The outcomes of this analysis are presented in Table 5.

Table 5 shows that FEPE has significant negative impacts on ACEs. Specifically, in the model (1)–(4), the coefficients of FEPE are significantly negative, which has confirmed the hypothesis 1: FEPE can reduce ACEs. The reason may be that FEPE can bring more the use of environmental protection facilities, equipment, and materials. The coefficients of variable Agricultural mechanization and Agricultural scale management are both significantly positive, indicating that agricultural mechanization and agricultural scale management will increase ACEs. The main reason of the finding may be that the use of agricultural machinery and equipment will cause the increase of carbon emissions. The coefficient of Planting structure is significantly negative, indicating that the “grain-oriented” planting structure will reduce ACEs. This may be due to the relatively less use of pesticides, agricultural films, fertilizers, etc. In food crops compared with other crops. The coefficient of Urbanization level is significantly positive, indicating that with the further acceleration of urbanization, the ACEs will also increase. The reason may be that urbanization makes the rural labor force show the characteristics of aging, feminization, and part-time employment. In order to avoid agricultural production reduction, farmers have invested a large amount of alternative production factors such as fertilizer, pesticide, agricultural film and mechanical facilities, resulting in large amount of ACEs. The coefficient of Consumption level of rural residents is significantly negative, indicating that with the improvement of rural residents’ consumption capacity, ACEs will be reduced. The reason may be that with the improvement of rural residents’ consumption capacity, there is a higher demand for the safety and quality of agricultural products, which urges farmers to adopt green low-carbon agricultural technology and reduce the input of pesticides and fertilizers, and thus it will improve agricultural green production efficiency and reduce ACEs.

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**TABLE 6 Heterogeneous impacts: different physical and geographical locations.**

| | (1) | (2) | (3) |
|---|---|---|---|
| | East area | Centre area | West area |
| FEPE | −3.83*** | −2.08** | −1.57 |
| | (−3.80) | (−2.37) | (-1.65) |
| Planting structure | −0.57*** | −0.39 | 0.67** |
| | (−3.30) | (−1.45) | (2.20) |
| Scale management of agricultural land | 0.03*** | 0.02*** | 0.01 |
| | (3.61) | (4.70) | (0.99) |
| Multiple crop index | 0.06 | −0.18*** | 0.08 |
| | (1.14) | (-2.80) | (1.63) |
| Consumption level of rural residents | −0.00*** | −0.00 | −0.00*** |
| | (−4.04) | (−0.78) | (-6.51) |
| Year Fixed Effect | Yes | Yes | Yes |
| Province Fixed Effect | Yes | Yes | Yes |
| *N* | 154 | 126 | 154 |
| adj. $R^2$ | 0.996 | 0.987 | 0.998 |

Note: The values in brackets are t statistics, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

## 4.2 Heterogeneity analysis

### 4.2.1 Based on natural geographical location

First of all, according to the division of the China Bureau of Statistics, 31 provinces and cities in China can be divided into the eastern, central, and western regions based on their geographical location and economic development level (Nie et al., 2019). According to the degree of economic development, they are divided into the eastern, central, and western regions. The environmental Kuznets theory tells us that there may be an inverted U-shaped relationship between the degree of economic development and carbon emissions. Therefore, it is necessary to distinguish three major regions and examine the heterogeneous impacts of FEPE on ACEs.

Table 6 reveals that FEPE exhibits a significant inhibitory effect on ACEs within the eastern and central regions, while its inhibitory effect is not statistically significant in the western regions. Specifically, in model (1) and model (2), the coefficients in front of the FEPE variable are −3.83 and −2.08 respectively, both of which are significant. In contrast, in model (3), the coefficients in front of the FEPE variable are both insignificant, which indicates that for the eastern and central regions, FEPE has a significant inhibitory effect on ACEs. However, this inhibitory impact is not discernible in the western regions. This variation can potentially be attributed to the heightened policy responsiveness of farmers in the central and eastern regions, owing to improved Internet infrastructure and expedited information dissemination. Consequently, as fiscal allocation towards environmental protection increases, farmers in these regions are more inclined to adopt corresponding technological measures aimed at diminishing ACEs.

### 4.2.2 Based on whether it is the main grain producing area

The main grain producing areas include Jiangsu, Inner Mongolia, Hebei, Henan, Shandong, Heilongjiang, Jilin, Liaoning, Anhui, Hubei, Hunan, Jiangxi and Sichuan. We also divide the samples into main grain producing areas and non-main grain producing areas and investigate potential heterogeneous impacts.

Table 7 shows that although the impact of FEPE on ACEs in major grain-producing areas is higher than that in non-major grain-producing areas, the difference is insignificant. It reveals that there are no differences among the impacts of FEPE on ACEs.

### 4.2.3 Based on different degree of ACEs

This paper further discusses the heterogeneous impacts of FEPE on ACEs under different quantiles of ACEs, which is shown in Table 8.

Table 8 shows that, the negative impact of FEPE on ACEs is significant at the high point, not at the low point. The coefficient of FEPE is significant at the 0.5, 0.7, and 0.9 quantiles, while not significant at the 0.1 and 0.3 quantiles. This shows that in provinces with relatively "high carbon emissions", the FEPE policy plays a significant role in reducing carbon emissions. The possible explanation lies in the agricultural production mode's susceptibility to path dependence. In provinces with relatively low carbon emissions, the scope for further ACE reduction is considerably constrained, rendering emissions reduction a challenging endeavor. At this time, the carbon emission reduction will also rely more on coordinated policies other than FEPE.

**TABLE 7 Heterogeneous impacts: main grain producing areas and non-main grain producing areas.**

| | (1) | (2) | (3) |
|---|---|---|---|
| | Grain producing area | Not grain producing area | All samples |
| FEPE | −4.03*** | −3.51*** | −4.09*** |
| | (−5.09) | (−4.84) | (−6.56) |
| Planting structure | −0.69*** | −0.13 | −0.21** |
| | (−3.27) | (−0.84) | (−1.99) |
| Scale management of agricultural land | 0.02*** | 0.01** | 0.02*** |
| | (5.73) | (2.28) | (5.06) |
| Multiple crop index | −0.17*** | 0.07 | 0.04 |
| | (−3.08) | (1.65) | (1.32) |
| Consumption level of rural residents | −0.00 | −0.00*** | −0.00*** |
| | (−1.14) | (−10.99) | (−11.61) |
| FEPE*Grain production area | | | −0.37 |
| | | | (−0.34) |
| Year Fixed Effect | Yes | Yes | Yes |
| Province Fixed Effect | Yes | Yes | Yes |
| *N* | 182 | 252 | 434 |
| adj. $R^2$ | 0.981 | 0.995 | 0.996 |
| Inter-group coefficient difference test (*p*-value) | 0.527 (0.35) | | |

Note: The values in brackets are t statistics, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$, the inter-group coefficient difference test adopts Fisher combination test.

**TABLE 8 Heterogeneity effect: distribution effect.**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | 0.1 | 0.3 | 0.5 | 0.7 | 0.9 |
| FEPE | −5.144 | −5.039 | −21.446*** | −5.487** | −15.997** |
| | (−0.614) | (−0.614) | (−9.945) | (−2.339) | (−2.041) |
| Planting structure | 5.986 | −0.851 | 2.804*** | 2.046*** | −0.539 |
| | (1.281) | (−0.503) | (16.310) | (8.746) | (-0.619) |
| Scale management of agricultural land | −0.251* | −0.062 | 0.035*** | 0.052*** | 0.061** |
| | (−1.673) | (−1.221) | (9.171) | (2.715) | (2.209) |
| Multiple crop index | −0.231 | 0.370 | 0.932*** | 0.529*** | 0.092 |
| | (−0.225) | (0.783) | (34.530) | (10.425) | (0.257) |
| Consumption level of rural residents | 0.000 | −0.000 | −0.000** | −0.000* | 0.000 |
| | (0.485) | (−0.505) | (−2.415) | (−1.762) | (1.132) |
| *N* | 434 | 434 | 434 | 434 | 434 |

Note: The values in brackets are t statistics, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

TABLE 9 Mechanism analysis: agricultural non-point source pollution.

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Chemical fertilizer | Agricultural film | Diesel oil | Pesticide | Turn | Irrigate |
| FEPE | −331.93*** | −245.47*** | −334.43*** | −55.13** | −1.19* | −27.48 |
| | (-3.07) | (-5.29) | (-4.65) | (-2.20) | (-1.81) | (-0.59) |
| Planting structure | −63.92*** | −23.10** | −55.94*** | −26.74*** | −0.28** | 34.71*** |
| | (−3.00) | (−2.52) | (−3.94) | (−5.40) | (−2.18) | (3.78) |
| Scale management of agricultural land | 1.67** | 0.08 | 0.74* | −0.13 | 0.06*** | 2.12*** |
| | (2.58) | (0.28) | (1.71) | (−0.86) | (14.28) | (7.60) |
| Multiple crop index | −14.01** | 0.68 | 0.68 | −2.75** | −0.02 | −7.19*** |
| | (−2.36) | (0.27) | (0.17) | (−2.00) | (−0.62) | (−2.82) |
| Consumption level of rural residents | −0.00*** | −0.00** | 0.00** | −0.00*** | −0.00** | −0.00** |
| | (−5.59) | (−2.24) | (2.36) | (−5.26) | (−2.21) | (−1.98) |
| Year Fixed Effect | Yes | Yes | Yes | Yes | Yes | Yes |
| Province Fixed Effect | Yes | Yes | Yes | Yes | Yes | Yes |
| *N* | 434 | 434 | 434 | 434 | 434 | 434 |
| adj. $R^2$ | 0.988 | 0.969 | 0.936 | 0.977 | 0.995 | 0.980 |

Note: The values in brackets are t statistics, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

## 4.3 Mechanism analysis

Furthermore, we explore the mechanism how FEPE affects ACEs from two aspects: agricultural technological progress and agricultural non-point source pollution.

### 4.3.1 Agricultural technological progress

Our paper mainly uses the total agricultural machinery power to measure the progress of agricultural technology. We construct the panel intermediary effect model to test the impact of agricultural technology progress. The study found that fiscal expenditure on environmental protection could not significantly affect the progress of agricultural technology. Therefore, this paper believes that FEPE cannot affect ACEs by affecting agricultural technology progress (Because it is not significant, we do not list the results here). This may be due to the fact that in response to environmental regulation, farmers may increase their expenditure on pollution abatement, which implies that their investment in mechanization would be crowed out (Palmer et al., 1995; Greenstone, 2002).

### 4.3.2 Agricultural non-point source pollution

Table 9 shows that among the six sources of ACEs, FEPE has the largest inhibiting effect on ACEs from the use of agricultural diesel, fertilizer and film, followed by the use of pesticides and tillage, and has no significant inhibiting effect on ACEs from irrigation. Specifically, in the model (1)–(3), the coefficients in front of the variable FEPE are −331.93, −245.47, and −334.43, respectively, all of which are significant, while in the model (4)–(5), the coefficients in front of the variable FEPE are −55.13 and −1.19, respectively, and have passed the 5% and 10% significance test, which shows that the FEPE has higher inhibitory effect on the ACEs from agricultural diesel, fertilizer and film use than that from the use of pesticides and tillage. The coefficient in front of the FEPE variable in model (6) lacks significance, indicating that FEPE has no significant effect on ACEs from irrigation.

## 5 Discussion

This article collects panel data at the provincial level in China to illustrate the efficacy of FEPE in mitigating ACEs. The findings affirm that FEPE indeed leads to a reduction in ACEs. This consistency aligns with prior research, including the works of Xu et al. (Yang et al., 2022a; Fan et al., 2022) and so on, reinforcing the credibility of the Porter hypothesis and providing further affirmation of the effectiveness of government environmental governance within the agricultural domain. The government supports environmental infrastructure construction or some application construction projects, which may stimulate enterprises to engage in subsequent pollution control or energy conservation and emission reduction activities. Cooperating with mandatory means, local FEPE has a strong guiding role for enterprise environmental protection investment (Yang et al., 2022b). On the one hand, the increase of local FEPE will promote technological progress (Guo and Zhang, 2023; Wei et al., 2023), provide specialized environmental protection services to industry, reduce industrial environmental protection costs, and improve industrial technological efficiency (Deng et al., 2023); On the other hand, it will strengthen the environmental awareness of industrial enterprises and encourage them to build green industrial chains (Liu et al., 2021b), internalizing environmental protection costs. This not only helps to solve environmental externalization, but also can improve the production efficiency of industrial enterprises, enhance the competitiveness of the entire industry, and achieve industrial technology upgrading.

Based on previous studies (Fan et al., 2022), we also find that FEPE has heterogeneous effects across different regions, and the effectiveness of policy implementation is mainly in the eastern and central regions with high carbon emissions, rather than western regions with low emissions. The possible reason is that in regions with relatively backward economies, local governments still place promoting economic growth before environmental governance; the reason is that the regions with high carbon emissions receive government attention have more pressure to reduce carbon emissions. As for the mechanism how FEPE affects ACEs, this article finds that FEPE mainly affects ACEs through agricultural diesel, fertilizer, and film use, rather than the level of agricultural mechanization. This is also different from previous studies (Luo et al., 2023), which argued that environmental regulation can promote technology innovation. We find the impact of FEPE on ACEs in major grain-producing areas is higher than that in non-major grain-producing areas, but these differences are not statistically significant. In addition, the heterogeneous impacts of FEPE on ACEs at different quantiles are manifested as significant at the high point, but insignificant at the low point, which reveals that only in provinces with relatively "high carbon emissions", FEPE can play a significant role in reducing ACEs. It is consistent with the research of Hong et al. (2022), which argues that the negative impact is more pronounced for non-heavily polluted regions.

Considering the spatial spillover effect of environmental pollution, we can collect more abundant data in the future (such as data from more segmented regions). This expanded dataset can then be used to formulate spatial econometric models to investigate the influence of FEPE on ACEs. In addition, policy evaluation is also one of the leading research directions, and to explore the impact of specific FEPE policies on ACEs can provide reference for government to formulate corresponding fiscal policies. Studying the impact of FEPE policies on farmers' behavior is a more worthwhile study, and we will further explore this aspect in the future.

# 6 Conclusion

To investigate whether FEPE can reduce ACEs, whether there are any heterogenous impacts among different regions and how FEPE affects ACEs, we have gathered panel data at the provincial level in China from 2007 to 2020 and used the ordinary least squares method to examine the impacts of FEPE on ACEs. The conclusions are as follows: To investigate whether FEPE can reduce ACEs, whether there are any heterogenous impacts among different regions and how to reduce ACEs, we have gathered panel data at the provincial level in China from 2007 to 2020 and used the ordinary least squares method to examine the impacts of FEPE on ACEs. The conclusions are as follows: FEPE has significant negative impacts on ACEs; And in different regions FEPE has heterogeneous impacts on ACEs, which shows that it has a significant impact on the eastern and central regions and provinces with relatively "high" carbon emissions, while it has no significant impact in the western regions and the "low" carbon emissions regions; Further mechanism analysis shows that the impact of FEPE on ACEs is mainly manifested in its inhibiting effect on agricultural diesel, fertilizer and film use of carbon emissions. The research findings hold substantial significance in guiding practical efforts aimed at diminishing ACEs.

Building upon the aforementioned conclusions, we put forward the following policy recommendations:

- First of all, Chinese government should guarantee the enduring stability of investments in environmental protection. It is imperative to secure an unbroken stream of funding for environmental safeguarding, originating from local government sources. There is a growing need to gradually augment financial allocations for environmental protection at all administrative tiers, thereby enhancing the proportion of such allocations within the broader framework of government budgetary disbursements.
- Secondly, it is essential to streamline the framework of fiscal allocations designated for environmental protection. To optimize the efficacy of environmental protection funding, a more nuanced approach is warranted in the ongoing execution of energy conservation and emission reduction initiatives. This could involve creating distinct funds for carbon emission control and specialized management interventions. Concurrently, the allocation structure for environmental protection expenditure should remain attuned to contemporary imperatives, forging a close alignment with China's present ecological context. Timely inclusions of essential projects and the pruning of superfluous elements are imperative, with a parallel consolidation of duplicate accounts for a more efficient system.
- Thirdly, it is imperative to develop viable strategies for mitigating ACEs that take into account the regional disparities in resource endowment. These strategies should involve adjusting the grain planting structures in primary grain-producing regions and harnessing the resource advantages of non-primary grain-producing areas. In the eastern plain region, expanding the scale of grain cultivation could be advantageous, while also leveraging the carbon reduction potential of the digital economy. In the southwestern region, the promotion of intercropping corn and soybeans can enhance soybean production capabilities, concurrently facilitating nitrogen fixation and fertilizer utilization. Additionally, attention should be directed towards the role of FEPE in stimulating the advancement of agricultural scientific and technological innovation.

In addition, this article also has several limitations: Firstly, the fiscal decentralization system in China is usually described as a three-level fiscal decentralization, which refers to the decentralization relationship between the central government, provincial governments, and local governments. Focusing solely on analyzing the influence of FEPE at the provincial level is insufficient. These limitations impel me to undertake further research in the future. Secondly, this study predominantly conducts empirical analysis of the FEPE's impact on ACEs from a macro perspective, lacking a comprehensive examination of micro mechanisms. These limitations will serve as a foundation for guiding my subsequent research endeavors.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/Supplementary Material.

## Author contributions

Conceptualization, SW and XC; methodology, SW and XC; software, SW and XC; validation, SW and XC; formal analysis, SW and XC; investigation, SW and XC; resources, SW and XC; data curation, SW and XC; writing—original draft preparation, SW and XC; writing—review and editing, SW and XC; visualization, SW and XC; supervision, SW and XC; project administration, SW and XC; funding acquisition, SW and XC. All authors contributed to the article and approved the submitted version.

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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.

## Publisher's note



## References

Abbas, A., Waseem, M., Ahmad, R., khan, K. A., Zhao, C., and Zhu, J. (2022a). Sensitivity analysis of greenhouse gas emissions at farm level: Case study of grain and cash crops. *Environ. Sci. Pollut. Res.* 29 (54), 82559–82573. doi:10.1007/s11356-022-21560-9

Abbas, A., Zhao, C., Waseem, M., Ahmed khan, K., and Ahmad, R. (2022b). Analysis of energy input–output of farms and assessment of greenhouse gas emissions: A case study of cotton growers. *Front. Environ. Sci.* 9. doi:10.3389/fenvs.2021.826838

Abdulai, A., and Huffman, W. (2014). The adoption and impact of soil and water conservation technology: An endogenous switching regression application. *Land Econ.* 90 (1), 26–43. doi:10.3368/le.90.1.26

Adewuyi, A. O. (2016). Effects of public and private expenditures on environmental pollution: A dynamic heterogeneous panel data analysis. *Renew. Sustain. Energy Rev.* 65, 489–506. doi:10.1016/j.rser.2016.06.090

Ali, G., and Nitivattananon, V. (2012). Exercising multidisciplinary approach to assess interrelationship between energy use, carbon emission and land use change in a metropolitan city of Pakistan. *Renew. Sustain. Energy Rev.* 16 (1), 775–786. doi:10.1016/j.rser.2011.09.003

Ambec, S., and Barla, P. (2002). A theoretical foundation of the Porter hypothesis. *Econ. Lett.* 75 (3), 355–360. doi:10.1016/s0165-1765(02)00005-8

Bai, Y., Deng, X., Jiang, S., Zhao, Z., and Miao, Y. (2019). Relationship between climate change and low-carbon agricultural production: A case study in Hebei province, China. *Ecol. Indic.* 105, 438–447. doi:10.1016/j.ecolind.2018.04.003

Bashir, M. A., Dengfeng, Z., Bashir, M. F., Rahim, S., and Xi, Z. (2023). Exploring the role of economic and institutional indicators for carbon and GHG emissions: Policy-based analysis for OECD countries. *Environ. Sci. Pollut. Res. Int.* 30 (12), 32722–32736. doi:10.1007/s11356-022-24332-7

Chen, Y., Miao, J., and Zhu, Z. (2021). Measuring green total factor productivity of China's agricultural sector: A three-stage SBM-DEA model with non-point source pollution and CO2 emissions. *J. Clean. Prod.* 318, 128543. doi:10.1016/j.jclepro.2021.128543

Deng, H., Zheng, W., Shen, Z., and Štreimikienė, D. (2023). Does fiscal expenditure promote green agricultural productivity gains: An investigation on corn production. *Appl. Energy* 334, 120666. doi:10.1016/j.apenergy.2023.120666

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

Elahi, E., Khalid, Z., Tauni, M. Z., Zhang, H., and Lirong, X. (2022b). Extreme weather events risk to crop-production and the adaptation of innovative management strategies to mitigate the risk: A retrospective survey of rural Punjab, Pakistan. *Technovation* 117, 102255. doi:10.1016/j.technovation.2021.102255

Elahi, E., Khalid, Z., and Zhang, Z. (2022a). Understanding farmers' intention and willingness to install renewable energy technology: A solution to reduce the environmental emissions of agriculture. *Appl. Energy* 309, 118459. doi:10.1016/j.apenergy.2021.118459

Fan, W., Li, L., Wang, F., and Li, D. (2020). Driving factors of CO2 emission inequality in China: The role of government expenditure. *China Econ. Rev.* 64, 101545. doi:10.1016/j.chieco.2020.101545

Fan, W., Yan, L., Chen, B., Ding, W., and Wang, P. (2022). Environmental governance effects of local environmental protection expenditure in China. *Resour. Policy* 77, 102760. doi:10.1016/j.resourpol.2022.102760

Galinato, G. I., and Galinato, S. P. (2016). The effects of government spending on deforestation due to agricultural land expansion and CO2 related emissions. *Ecol. Econ.* 122, 43–53. doi:10.1016/j.ecolecon.2015.10.025

Greenstone, M. (2002). The impacts of environmental regulations on industrial activity: Evidence from the 1970 and 1977 clean air act amendments and the census of manufactures. *J. Political Econ.* 110 (6), 1175–1219. doi:10.1086/342808

Guan, D., Hubacek, K., Weber, C. L., Peters, G. P., and Reiner, D. M. (2008). The drivers of Chinese CO2 emissions from 1980 to 2030. *Glob. Environ. Change* 18 (4), 626–634. doi:10.1016/j.gloenvcha.2008.08.001

Guo, L., Zhao, S., Song, Y., Tang, M., and Li, H. (2022). Green finance, chemical fertilizer use and carbon emissions from agricultural production. *Agriculture* 12 (3), 313. doi:10.3390/agriculture12030313

Guo, Z., and Zhang, X. (2023). Carbon reduction effect of agricultural green production technology: A new evidence from China. *Sci. Total Environ.* 874, 162483. doi:10.1016/j.scitotenv.2023.162483

Haider, A., Bashir, A., and Husnain, M. I. U. (2020). Impact of agricultural land use and economic growth on nitrous oxide emissions: Evidence from developed and developing countries. *Sci. Total Environ.* 741, 140421. doi:10.1016/j.scitotenv.2020.140421

Halkos, G. E., and Paizanos, E. A. (2013). The effect of government expenditure on the environment:An empirical investigation. *Ecol. Econ.* 91, 48–56. doi:10.1016/j.ecolecon.2013.04.002

Hamamoto, M. (2006). Environmental regulation and the productivity of Japanese manufacturing industries. *Resour. Energy Econ.* 28 (4), 299–312. doi:10.1016/j.reseneeco.2005.11.001

He, L., Wu, M., Wang, D., and Zhong, Z. (2018). A study of the influence of regional environmental expenditure on air quality in China: The effectiveness of environmental policy. *Environ. Sci. Pollut. Res. Int.* 25 (8), 7454–7468. doi:10.1007/s11356-017-1033-8

Hinz, R., Sulser, T. B., Huefner, R., Mason-D'Croz, D., Dunston, S., Nautiyal, S., et al. (2020). Agricultural development and land use change in India: A scenario analysis of trade-offs between UN sustainable development goals (SDGs). *Earth's Future* 8 (2). doi:10.1029/2019ef001287

Holka, M., Kowalska, J., and Jakubowska, M. (2022). Reducing carbon footprint of agriculture—can organic farming help to mitigate climate change? *Agriculture* 12 (9), 1383. doi:10.3390/agriculture12091383

Hong, Y., Jiang, X., Shi, B., and Yu, C. (2022). Do fiscal environmental protection expenditures crowd out corporate environmental protection investments? *Sustainability* 14 (20), 13608. doi:10.3390/su142013608

Huang, J.-T. (2018). Sulfur dioxide (SO2) emissions and government spending on environmental protection in China - evidence from spatial econometric analysis. *J. Clean. Prod.* 175, 431–441. doi:10.1016/j.jclepro.2017.12.001

IPCC (2007). *Climate change 2007: Mitigation: Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change: Summary for policymakers and technical summary*. Cambridge: Cambridge University Press.

Johnson, J. M., Franzluebbers, A. J., Weyers, S. L., and Reicosky, D. C. (2007). Agricultural opportunities to mitigate greenhouse gas emissions. *Environ. Pollut.* 150 (1), 107–124. doi:10.1016/j.envpol.2007.06.030

Laborde, D., Mamun, A., Martin, W., Pineiro, V., and Vos, R. (2021). Agricultural subsidies and global greenhouse gas emissions. *Nat. Commun.* 12 (1), 2601. doi:10.1038/s41467-021-22703-1

Li, B., Zhang, J., and Li, H. (2011). Research on spatial-temporal characteristics and affecting factors decomposition of agricultural carbon emission in China. *China Popul. Resour. Environ.* 21 (8), 80–86. doi:10.3969/j.issn.1002-2104.2011.08.013

Li, L., Han, J., and Zhu, Y. (2023). Does environmental regulation in the form of resource agglomeration decrease agricultural carbon emissions? Quasi-Natural experimental on high-standard farmland construction policy. *J. Clean. Prod.* 420, 138342. doi:10.1016/j.jclepro.2023.138342

Li, S., and Wang, Z. (2023). Time, spatial and component characteristics of agricultural carbon emissions of China. *Agriculture* 13 (1), 214. doi:10.3390/agriculture13010214

Liu, D., Zhu, X., and Wang, Y. (2021a). China's agricultural green total factor productivity based on carbon emission: An analysis of evolution trend and influencing factors. *J. Clean. Prod.* 278, 123692. doi:10.1016/j.jclepro.2020.123692

Liu, Z., Lang, L., Hu, B., Shi, L., Huang, B., and Zhao, Y. (2021b). Emission reduction decision of agricultural supply chain considering carbon tax and investment cooperation. *J. Clean. Prod.* 294, 126305. doi:10.1016/j.jclepro.2021.126305

López, R., Galinato, G. I., and Islam, A. (2011). Fiscal spending and the environment: Theory and empirics. *J. Environ. Econ. Manag.* 62 (2), 180–198. doi:10.1016/j.jeem.2011.03.001

Luo, G., Guo, J., Yang, F., and Wang, C. (2023). Environmental regulation, green innovation and high-quality development of enterprise: Evidence from China. *J. Clean. Prod.* 418, 138112. doi:10.1016/j.jclepro.2023.138112

Midingoyi, S. k. G., Kassie, M., Muriithi, B., Diiro, G., and Ekesi, S. (2018). Do farmers and the environment benefit from adopting integrated pest management practices? Evidence from Kenya. *J. Agric. Econ.* 70 (2), 452–470. doi:10.1111/1477-9552.12306

Moshiri, S., and Daneshmand, A. (2020). How effective is government spending on environmental protection in a developing country? *J. Econ. Stud.* 47 (4), 789–803. doi:10.1108/jes-12-2018-0458

Mosier, A. R., Duxbury, J. M., Freney, J. R., Heinemeyer, O., Minami, K., and Johnson, D. E. (1998). Mitigating agricultural emissions of methane. *Clim. Change* 40 (1), 39–80. doi:10.1023/a:1005338731269

Nie, Y., Li, Q., Wang, E., and Zhang, T. (2019). Study of the nonlinear relations between economic growth and carbon dioxide emissions in the Eastern, Central and Western regions of China. *J. Clean. Prod.* 219, 713–722. doi:10.1016/j.jclepro.2019.01.164

Northrup, D. L., Basso, B., Wang, M. Q., Morgan, C. L. S., and Benfey, P. N. (2021). Novel technologies for emission reduction complement conservation agriculture to achieve negative emissions from row-crop production. *Proc. Natl. Acad. Sci. U. S. A.* 118 (28), e2022666118. doi:10.1073/pnas.2022666118

Palmer, K., Oates, W. E., and Portney, P. R. (1995). Tightening environmental standards: The benefit-cost or the No-cost paradigm? *J. Econ. Perspect.* 9 (4), 119–132. doi:10.1257/jep.9.4.119

Peter, C., Helming, K., and Nendel, C. (2017). Do greenhouse gas emission calculations from energy crop cultivation reflect actual agricultural management practices? – a review of carbon footprint calculators. *Renew. Sustain. Energy Rev.* 67, 461–476. doi:10.1016/j.rser.2016.09.059

Porter, M. E. (1991). Essay. *Sci. Am.* 264 (4), 168. doi:10.1038/scientificamerican0491-168

Porter, M. E., and Vanderlinde, C. (1995). Toward a new conception of the environment-competitiveness relationship. *J. Econ. Perspect.* 9 (4), 97–118. doi:10.1257/jep.9.4.97

Qin, L., Liu, S., Hou, Y., Zhang, Y., Wu, D., and Yan, D. (2023). The spatial spillover effect and mediating effect of green credit on agricultural carbon emissions: Evidence from China. *Front. Earth Sci.* 10. doi:10.3389/feart.2022.1037776

Raihan, A., and Tuspekova, A. (2022). Dynamic impacts of economic growth, energy use, urbanization, agricultural productivity, and forested area on carbon emissions: New insights from Kazakhstan. *World Dev. Sustain.* 1, 100019. doi:10.1016/j.wds.2022.100019

Raza, Z. (2020). Effects of regulation-driven green innovations on short sea shipping's environmental and economic performance. *Transp. Res. Part D Transp. Environ.* 84, 102340. doi:10.1016/j.trd.2020.102340

Ren, C., Liu, S., van Grinsven, H., Reis, S., Jin, S., Liu, H., et al. (2019). The impact of farm size on agricultural sustainability. *J. Clean. Prod.* 220, 357–367. doi:10.1016/j.jclepro.2019.02.151

Rubashkina, Y., Galeotti, M., and Verdolini, E. (2015). Environmental regulation and competitiveness: Empirical evidence on the Porter Hypothesis from European manufacturing sectors. *Energy Policy* 83, 288–300. doi:10.1016/j.enpol.2015.02.014

Sheng, W., Wan, L., and Wang, C. (2022). The spillover effect of fiscal environmental protection spending on residents' medical and healthcare expenditure: Evidence from China. *Environ. Geochem Health* 44 (9), 2975–2986. doi:10.1007/s10653-021-01146-z

Wang, R., Zhang, Y., and Zou, C. (2022). How does agricultural specialization affect carbon emissions in China? *J. Clean. Prod.* 370, 133463. doi:10.1016/j.jclepro.2022.133463

Wei, L., Lin, B., Zheng, Z., Wu, W., and Zhou, Y. (2023). Does fiscal expenditure promote green technological innovation in China? Evidence from Chinese cities. *Environ. Impact Assess. Rev.* 98, 106945. doi:10.1016/j.eiar.2022.106945

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 Chen, F. (2007). Effects of conservation tillage on net carbon flux from farmland ecosystems. *Chin. J. Eco-Agriculture* (12), 2035–2039. doi:10.1360/biodiv.070085

Xie, Z., Teng, X., Liu, F.-p., and Chiu, Y.-h. (2021). The impact of China's financial expenditure on energy and carbon emission efficiency: Applying a meta-dynamic non-radial directional distance function. *Energy & Environ.* 34 (1), 155–175. doi:10.1177/0958305x211053913

Xu, C., Xu, Y., Chen, J., Huang, S., Zhou, B., and Song, M. (2023). Spatio-temporal efficiency of fiscal environmental expenditure in reducing CO(2) emissions in China's cities. *J. Environ. Manage* 334, 117479. doi:10.1016/j.jenvman.2023.117479

Yang, C.-H., Tseng, Y.-H., and Chen, C.-P. (2012). Environmental regulations, induced R&D, and productivity: Evidence from Taiwan's manufacturing industries. *Resour. Energy Econ.* 34 (4), 514–532. doi:10.1016/j.reseneeco.2012.05.001

Yang, J., Shi, D., and Yang, W. (2022b). Stringent environmental regulation and capital structure: The effect of NEPL on deleveraging the high polluting firms. *Int. Rev. Econ. Finance* 79, 643–656. doi:10.1016/j.iref.2022.02.020

Yang, N., Sun, X., and Qi, Q. (2022a). Impact of factor quality improvement on agricultural carbon emissions: Evidence from China's high-standard farmland. *Front. Environ. Sci.* 10. doi:10.3389/fenvs.2022.989684

Yu, Y., Huang, Y., and Zhang, W. (2013). Projected changes in soil organic carbon stocks of China's croplands under different agricultural managements, 2011–2050. *Agric. Ecosyst. Environ.* 178, 109–120. doi:10.1016/j.agee.2013.06.008

Zhang, J., Zhang, H., and Gong, X. (2022). Government's environmental protection expenditure in China: The role of Internet penetration. *Environ. Impact Assess. Rev.* 93, 106706. doi:10.1016/j.eiar.2021.106706

Zhang, L., Pang, J., Chen, X., and Lu, Z. (2019a). Carbon emissions, energy consumption and economic growth: Evidence from the agricultural sector of China's main grain-producing areas. *Sci. Total Environ.* 665, 1017–1025. doi:10.1016/j.scitotenv.2019.02.162

Zhang, T., Yang, Y., Ni, J., and Xie, D. (2019b). Adoption behavior of cleaner production techniques to control agricultural non-point source pollution: A case study in the three gorges reservoir area. *J. Clean. Prod.* 223, 897–906. doi:10.1016/j.jclepro.2019.03.194

Zhao, R., Liu, Y., Tian, M., Ding, M., Cao, L., Zhang, Z., et al. (2018). Impacts of water and land resources exploitation on agricultural carbon emissions: The water-land-energy-carbon nexus. *Land Use Policy* 72, 480–492. doi:10.1016/j.landusepol.2017.12.029

Zou, L., Liu, Y., Wang, Y., and Hu, X. (2020). Assessment and analysis of agricultural non-point source pollution loads in China: 1978-2017. *J. Environ. Manage* 263, 110400. doi:10.1016/j.jenvman.2020.110400