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Exploring the role of environmental literacy and social norms in farmers' LMTT adoption: evidence from China

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Abstract

Purpose – Climatic changes caused by greenhouse gases (GHGs) emissions are an urgent challenge for all regions around the globe while the livestock sector is an important source of GHGs emissions. The adoption of low-carbon manure treatment technology (LMTT) by farmers is emerging as an effective remedy to neutralize the carbon emissions of livestock. This paper aims to incorporate environmental literacy and social

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Retraction notice: The publisher of the *International Journal of Climate Change Strategies and Management* wishes to retract the article by Songqing Li, Xuexi Huo, Ruishi Si, Xueqian Zhang, Yumeng Yao, Li Dong (2022), "Exploring the role of environmental literacy and social norms in farmers' LMTT adoption: evidence from China", published in the *International Journal of Climate Change Strategies and Management* as part of a special issue, Vol. ahead-of-print, No. ahead-of-print, https://doi.org/10.1108/IJCCSM-12-2021-0138. It has come to our attention that there are concerns that the peer review process was compromised; as a result, the standard of the article does not meet those expected by the journal and the findings cannot be relied upon. The issue is with the review process, and there is no evidence that the authors were involved or concerns regarding the authorship. The authors would like it to be noted that they are not in agreement with this retraction. The publisher of the journal sincerely apologises to the readers.

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norms into the analysis framework, with the aim of exploring the impact of environmental literacy and social norms on farmers' adoption of LMTT and finally reduce GHGs emission and climate effects.

Design/methodology/approach – This research survey is conducted in Hebei, Henan and Hubei provinces of China. First, this research measures environmental literacy from environmental cognition, skill and responsibility and describes social norms from descriptive and imperative social norms. Second, this paper explores the influence of environmental literacy and social norms on the adoption of LMTT by farmers using the logit model. Third, Logit model's instrumental approach, i.e. IV-Logit, is applied to address the simultaneous biases between environmental skill and farmers' LMTT adoption. Finally, the research used a moderating model to analyze feasible paths of environmental literacy and social norms that impact the adoption of LMTT by farmers.

Findings – The results showed that environmental literacy and social norms significantly and positively affect the adoption of LMTT by farmers. In particular, the effects of environmental literacy on the adoption of LMTT by farmers are mainly contributed by environmental skill and responsibility. The enhancement of social norms on the adoption of LMTT by farmers is mainly due to the leading role of imperative social norms. Meanwhile, if the endogeneity caused by the reverse effect between environmental skill and farmers' LMTT adoption is dealt with, the role of environmental skill will be weakened. Additionally, LMTT technologies consist of energy and resource technologies. Compared to energy technology, social norms have a more substantial moderating effect on environmental literacy, affecting the adoption of farmer resource technology.

Originality/value – To the best of the authors' knowledge, a novel attempt is made to examine the effects of environmental literacy and social norms on the adoption of LMTT by farmers, with the objective of identifying more effective factors to increase the intensity of LMTT adoption by farmers.

Keywords LMTT adoption, Energy technology, Resource technology, Environmental literacy, Social norms

Paper type Research paper

1. Introduction

1.1 The relationship between global carbon emissions and livestock manure

The livestock sector is a key part of the morden agricultural industry and plays an essential role in meeting the growing demand for meat-derived food, improving the dietary structure of residents and promoting the adjustment of the modern agricultural structure (Oreggioni *et al.*, 2021). Also, it has become an engine for some developing countries to eliminate poverty traps, increase family income and improve their welfare (Faisal *et al.*, 2021). However, the large amount of livestock manure simultaneously imposes numerous environmental challenges such as greenhouse gas (GHG) emissions, which further contributes to global climate changes and extreme disasters such as persistent droughts and severe floods (Jahangir *et al.*, 2022; Steinfeld *et al.*, 2006). According to the reports of the United Nations, the GHGs emitted annually from the livestock sector represent 29% of the emissions induced by the agricultural sector globally (Rehman *et al.*, 2021). Many scholars have confirmed the causal relationship between livestock manure and GHGs emissions, especially carbon emissions (Awasthi *et al.*, 2022; Wang *et al.*, 2021). Just as Zubair *et al.* (2020) reported that GHGs such as CO_2, CH_4 and N_2O are mainly produced from the livestock industry during livestock manure treatment. In this vein, reducing carbon emissions from the livestock industry by strengthening the environment's supervision and enhancing low-carbon manure treatment have become a consensus of all countries (Sakadevan and Nguyen, 2017).

1.2 China's carbon emissions and low-carbon manure treatment

Over the past 40 years, together with urbanization and industrialization in China, the increase in GHGs has exacerbated climate effects, such as an increase in extreme precipitation and abnormal high temperature (Zhang and Maroulis, 2021). In 2020, China's carbon emissions will reach 9.899 billion tons, accounting for 30.7% of global carbon emissions, and China has become the world's largest carbon emitter. Therefore, strengthening China's carbon emission governance is conducive to compressing global carbon emissions and alleviating global warming and climate affects (Dong *et al.*, 2018). As the world's primary meat consumer country, China's livestock industry has become an essential source of GHG emissions (Piwowar, 2019). In 2019, the total carbon emissions of China's livestock sector have exceeded 14 million tons, accounting for 50% of agricultural carbon emissions (Yao *et al.*, 2020). Consequently, since 2012, the government has successively implemented regulatory policies such as legal penalties, financial subsidies and technical guidance to restrict or motivate farmers to adopt a series of low-carbon manure treatment technology (LMTT) to reduce manure carbon emissions (Wang *et al.*, 2022). Unfortunately, the rate of farmers' LMTT adoption is still low.

1.3 Literature review on the low-carbon manure treatment technology and influencing factors of farmers' low-carbon manure treatment technology adoption

Existing studies have confirmed that increasing farmers' adoption of LMTT plays a vital role in reducing manure-induced carbon emissions (Wang *et al.*, 2018). LMTT mainly includes energy technology, such as biogas fermentation, and resource technology, such as compost fermentation. The advantage of LMTT is to reduce carbon emissions by turning livestock manure into renewable energy resources. It ultimately drives shifts the livestock economy toward a low carbon emission and climate-adaptive society (Roubík and Mazancová, 2019). Specifically, the advantages of biogas fermentation are the production of clean biogas fuel, the reduction of foul smell and the decrease of GHG emissions induced by manure (Rajendran *et al.*, 2012). According to Molino *et al.* (2013), it is found that biogas produced by anaerobic digestion of small biogas digesters can provide a clean, efficient and low-cost renewable energy source. In a recent study, Awasthi *et al.* (2019) demonstrated that compost fermentation, a biological treatment technology, can stimulate the response of aerobic microorganisms and reduce the unfavorable effects of livestock manure, that is, foul odor, carbon emissions and transmission of bacteria or viruses.

Although the previous literature did not directly analyze the influencing factors of farmers' adoption of LMTT, many scholars have explored the driving factors of farmers choosing manure biogas or compost fermentation. The empirically identified influencing factors mainly include individual characteristics, such as gender, age, education level and political identity (He *et al.*, 2022); cognitive characteristics, such as environmental attitude, risk preference, risk awareness and health perception (Goldfarb *et al.*, 2022); family and business characteristics, such as population size, family labor, farmland area, breeding scale, livestock housing area, livestock market price and cooperative participation (Zhang *et al.*, 2022); social characteristics, such as relationship network, peer effect, social supervision and group pressure (Kreidenweis *et al.*, 2021); policy conditions, such as government supervision, financial support, credit rationing and technical services (Rehman *et al.*, 2021). Farmers' manure biogas and compost fermentation treatment are environment-friendly behaviors and have typical public goods attributes, which probably cause farmers' adverse selection and moral hazard (Spielmeyer, 2018). Although previous studies have focused on the impact of government regulations on the farmers' composting or fermentation treatment, there is little reasons recognized and accepted widely, which still hinder the increase in the rate of farmers' LMTT adoption.

1.4 Environmental literacy and social norms offer new ideas to solve the issue

The farmer's environmentally friendly behavior is the combined action of internal and external factors (Unay-Gailhard and Bojnec, 2021). Previous studies have confirmed that environmental literacy has expanded the farmer's 'behavioral attitude' within the framework of the theory of planned behavior and played an essential role in driving farmers' green production (Guo *et al.*, 2020). Meanwhile, accompanied by the diversified development of the social governance system, social norms have also become an essential supplement to government regulation and played a key role in guiding farmers' green production with low-cost and high-efficiency (Quan *et al.*, 2022). Consequently, the academic community has conducted many survey analyses on the role of environmental literacy and social norms in promoting the pro-environmental behavior of farmers (relevant literature in Table 1).

1.5 The innovation of this research

In summary, it can be found that, first, previous studies only measured environmental literacy and social norms from a certain level, and a complete indicator system has not yet been constructed. Second, the previous literature has not incorporated environmental literacy and social norms into a unified analysis framework of farmers' environmentally friendly behaviors, especially farmers' LMTT adoption. Finally, previous research has rarely explored the reverse causality and endogeneity between environmental literacy or social norms and farmers' behaviors. Consequently, the main innovations of this study are as follows: we innovatively measure environmental literacy from environmental cognition, skill and responsibility and describe social norms from descriptive and imperative norms. In addition, environmental literacy and social norms are incorporated in the unified analysis framework of farmers' LMTT adoption. Meanwhile, the IV-Logit model is used to deal with

Table 1. Relevant literature

Findings	Reference (s)
This research used 1,023 Chinese households' survey data, explored farmer environmental-friendly behaviors, including organic fertilizer application, and stated that environmental literacy, such as environmental responsibility, knowledge and skill, positively and significantly influences farmer environmental-friendly behaviors	Guo *et al.* (2020)
This research used data from rural inhabitants in the state of North Kordofan, Sudan and Chiang Mai Province and the local people believe that they are aware of their environment by using the concept of environmental literacy that may help to develop sustainable environmental management practices	Hares and Eskonheimo (2006)
This research used survey data collected from Zambia and reported that environmental literacy positively and significantly influences farmers' decision-making ability to lessen environmental degradation; The more farmers understand environmental degeneration and its consequences, the more likely they are to take certain measures to reduce the intensity of grazing	Wu and Mweemba (2010)
The study is based on a combination of survey and census data from 105 farmers in Switzerland and found that there is a significant impact of noncognitive skills on farmers' adoption of climate change mitigation measures	Kreft *et al.* (2021)
This research analyzed data from a randomized controlled trial (RCT) conducted with 1287 small-scale tea farmers in Vietnam and believed that significant impacts of the 50% price subsidy and experience sharing on farmers' adoption of organic fertilizer	Vu *et al.* (2020)
This research carried out by multistage random sampling and 130 framers from 30 villages in data from Fars counties, Iran, and found that perceived behavioral control, social and moral norms, as well as extension education had a significant effect on farmers' intent to continue producing clean and environmentally friendly compost technology	Rezaei-Moghaddam *et al.* (2020)
This research used data from the pilot area of pesticide packaging waste recycling in Jiangsu Province and concluded that descriptive and imperative social norms are essential factors influencing farmers' recycling behavior; social norms and economic incentives have complementary effects on farmers' recycling behavior	Li *et al.* (2021)
This research used survey data from 644 households in Gansu province and argued that social norms still have a significant negative influence on farmers' willingness to plant green manure and behavioral deviation	Shi and Zhang (2022)

possible endogenous issues between environmental skill and the adoption of LMTT by farmers. Additionally, the moderating effect of social norms on environmental literacy that influences farmers' adoption of LMTT is also explored. Finally, some policy implications are presented to promote the adoption of LMTT by farmers.

2. Theoretical background

2.1 The impact of environmental literacy on farmers' low-carbon manure treatment technology adoption

Several scholars have not yet reached a consensus on the definition of environmental literacy. Some authors have used different dimensions to define environmental literacy, such as McBride *et al.* (2013) reflected that environmental cognition is a basis of environmental literacy. Erdogan (2015) believed that environmental literacy is composed of environmental skill and responsibility. Following Maurer and Bogner (2020), we used three dimensions of environmental literacy in the current study, that is, environmental cognition, skill and responsibility.

Environmental cognition reflects the individual's feeling and perception of knowledge and information about the environment. According to cognitive behavior theory, individual cognition plays a vital role in manifesting an individual's behavior, and thus, valid cognition motivates individuals to implement environmentally friendly behaviors. Just as Li, Ren *et al.* (2020) argued that environmental cognition has a significant impact on individual ecological consumption. In a recent study by Lu *et al.* (2020), it is found that environmental cognition can encourage farmers to adopt the crop straw recycling behavior. Consequently, it is hypothesized that if farmers' environmental cognition level is higher, they will hold a positive attitude towards environmental issues and tend to adopt the LMTT.

Similarly, the other dimension, such as environmental skill, is also considered a key determinant in modifying the environmental behaviors of farmers. With regard to the relationship between farmer skill and behavior, Wang *et al.* (2017) found that skill training and guidance from the government and even relatives significantly influence farmers' behavior of using pesticides. Similarly, Pinzone *et al.* (2019) believe that providing green-related skills for employees helps improve an organization's environmental performance. In this study, environmental skill refers to the ability of farmers to mitigate and lessen manure-induced pollution. In livestock and poultry breeding, the higher the level of environmental skill, the more skilled farmers will adopt environmental protection approaches, that is, the stronger the farmers' ability to solve manure-induced environmental pollution, the greater the possibility of adopting LMTT.

Lastly, environmental responsibility means the concentrated expression of individuals' attitudes, views, beliefs and values on environmental issues (Yang *et al.*, 2021). Individuals with strong environmental responsibility will have altruistic behavior tendencies toward negative environmental externalities (Hines and Hungerford, 1986; Pawaskar *et al.*, 2018). Ding *et al.* (2017) believed that the higher level of residents' environmental responsibility led individuals to implement energy-saving technologies. In agricultural farming, farmers are inclined to invest time and money to adopt the LMTT to reduce the adverse effects of production activities on the environment. It infers that farmers with a higher sense of environmental responsibility take economic benefits when making production decisions, pay close attention to the impact of self-behaviors on the public environment and tend to adopt the LMTT. On the basis of the above analysis, the following hypotheses are proposed.

H1. Environmental literacy exerts a positive and significant influence on farmers' adoption of LMTT.

H1a. Environmental cognition can promote the adoption of LMTT by farmers.

H1b. Environmental skill can drive the adoption of LMTT by farmers.

H1c. Environmental responsibility can encourage the adoption of LMTT by farmers.

2.2 The impact of social norms on farmers' low-carbon manure treatment technology adoption

Social norms are critical variables of reasoned action theory and planned behavior theory (Ajzen, 1991). These theories hold that social norms play a vital role in shaping behavioral intentions and affecting individual behaviors. Czajkowski *et al.* (2017) argued that morality and intrinsic motivation induced by social norms significantly influence the waste disposal behavior of households. Kim and Seock (2019) pointed out that altruism values affect the purchase of environmentally friendly products by individuals. In a recent study by Zeng *et al.* (2020), it is found that external incentives and social norms are significant determinants for rice farmers to implement reduced use of fertilizers and pesticides.

According to Cialdini *et al.* (1990), social norms are divided into descriptive and imperative norms. Descriptive social norms refer to what people actually do, that is, specific behaviors that have been implemented or are being implemented by most people in a group. Imperative social norms refer to what people think they should or should not do, such as the particular behavior that people agree or oppose in the social group. Descriptive social norms often affect people's behavior unconsciously; an individual's behavior is usually affected by the behavior of most people around them, but he or she doesn't notice it (Cialdini *et al.*, 2007). Imperative social norms strengthen the right and wrong judgment of specific behavior by most people in the group and further impact individual behavior choices. When descriptive and imperative norms favor individual behavior, then the probability of the individuals' behavior becomes the strongest.

Based on descriptive social norms, the present study infers that if some farmers without LMTT adoption live together with other farmers with LMTT adoption, they will follow the trend of adopting LMTT. The impact of imperative social norms on farmers is manifested by social pressure; farmer behavior is affected by public opinion around them. For example, when relatives, friends or neighbors believe that LMTT should be adopted, they will adopt it under public opinion pressure. On the basis of the above analysis, the following hypotheses are proposed.

H2. Social norms have a positive and significant impact on farmers' LMTT adoption.

H2a. Descriptive social norms have a positive impact on farmers' LMTT adoption.

H2b. Imperative social norms have a positive impact on farmers' LMTT adoption.

2.3 The moderating effect of social norms in environmental literacy affecting farmers' low-carbon manure treatment technology adoption

In China, farmers mainly exchange information related to agricultural production through social networks (Beaman and Dillon, 2018). Social norms generally act as a function of mutual trust and information exchange between individuals (Li *et al.*, 2021). When farmers have stronger social norms that are environmentally friendly, the relationship network is filled with more pro-environmental signs. Therefore, pro-environmental signs may moderate the impact of environmental literacy on the environmental behavior of farmers.

This article hypothesizes that farmers can also make behavioral adjustments based on the intensity of social norms when environmental literacy drives farmers to adopt the LMTT. Firstly, as for social norms of pro-environmental behaviors, environmental protection signs can be easily diffuse among farmers, so their judgment regarding environmental behaviors may alter according to other group members, who are also conducive to enhance farmers' LMTT awareness and prompt them to adopt LMTT actively. Second, social norms that transmit pro-environmental signs through the relationship network also disseminate environmental skill and interaction between environmental behaviors. When most farmers' environmental skills and environmental behaviors are harmonized, their environmental skills will be further improved and encouraged toward adopting the LMTT. Finally, with the rise of manure-induced pollution and the strengthening of environmental regulations, farmers have realized the environmental costs caused by opting for conventional production methods. When some farmers have a high sense of environmental responsibility, they also lead other farmers to shoulder environmental responsibility and adhere to the LMTT. On the basis of the above discussion, the following hypotheses are proposed in the current study. Besides, Figure 1 shows the theoretical analysis framework of this paper.

H3. Social norms have a positive moderating effect on the relationship between environmental literacy and farmers' LMTT adoption;

H3a. Social norms have a positive moderating effect on the relationship between environmental cognition and farmers' LMTT adoption;

H3b. Social norms have a positive moderating effect on the relationship between environmental skill and farmers' LMTT adoption;

H3c. Social norms have a positive moderating effect on the relationship between environmental responsibility and farmers' LMTT adoption.

The theoretical framework operationalize in the current study is shown in Figure 1.

3. Materials and methods

3.1 Sample selection

Data are obtained through a field survey from three provinces of China, i.e. Hebei, Henan and Hubei, from July to August 2018 and March 2019 (as shown in Figure 2). The sample

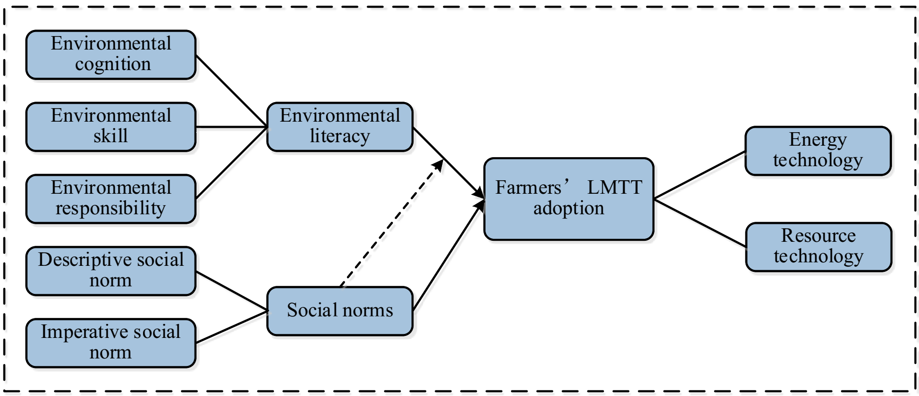

Figure 1.
The theoretical framework of this research

area's selection is mainly based on the fact that these provinces have large-scale pig farmers and the breeding industry is a pillar industry for regional economic development. In 2017, Hebei, Henan and Hubei had 35, 62 and 43 million pigs, which represented 5.0%, 9.0% and 6.0% of China's total pig raising. Furthermore, these provinces tend to adopt LMTT through policy interventions, including energy and resource technologies. Since 2012, sample regions have been pilot areas for the Chinese government's implementation of the manure carbon reduction strategy and the rate of farmer adoption of LMTT in sample counties and towns was considered the government's performance assessment. Therefore, the selection of three provinces as the research area is representative.

This paper used a combined sampling approach such as stratified and random sampling. The selection is made in the following steps as – two to four counties from each province are selected, then – three to five towns from each county are chosen. And finally, farmers are randomly selected from – five to seven villages for each town. Around 1,000 questionnaires are distributed in the study areas, and finally 941 valid samples were obtained after eliminating 59 invalid questionnaires, accounting for 94.10% of the total sample. According to the sample size, 320 farm households from Hebei, 314 from Henan, and 307 from Hubei were found to reflect the distribution of samples in the study regions evenly.

3.2 Outcome variable

The outcome variable in the current study is farmers' LMTT adoption, a discrete binary variable. If farmers adopt the LMTT, the value is 1; otherwise, the value is 0. In practice, due to the heterogeneity of government technology promotion and farmers' resource

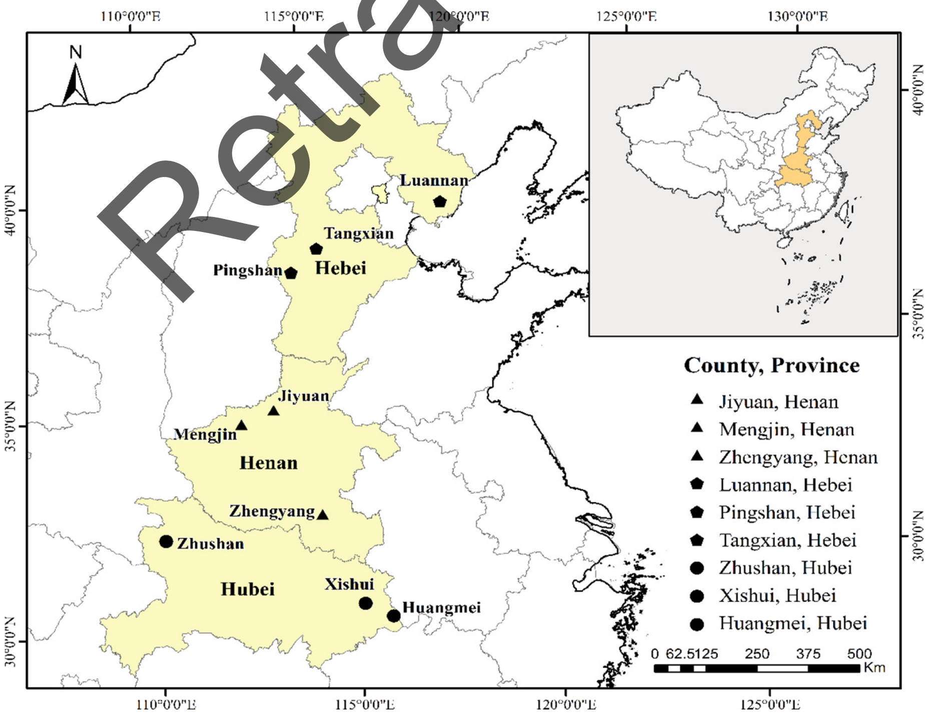

Figure 2.
Sample study area

endowments, based on different technical attributes, there are two types of LMTT, ie, energy technology (e.g. biogas fermentation) and resource technology (e.g. compost fermentation). Around 280 and 237 farmers adopt energy and resource technologies in the sample, representing 29.76% and 25.19% of the total sample, respectively. Additionally, different technologies need to invest in various production factors such as land, labor and equipment. Therefore, farmers do not choose both types of technologies simultaneously to implement. In addition, 424 farmers still choose traditional non-carbon reduction treatment, such as returning to the farmland directly or simply stacking. The statistics of farmers' technology adoption in different provinces are shown in Figure 3.

3.3 Explanatory variables

The core explanatory variables are environmental literacy (environmental cognition, skill and responsibility) and social norms (descriptive and imperative social norms) – the five-level Likert scale method is used for the measurement of the variables. Meanwhile, drawing on the views of Sorkun (2018), we used the arithmetic average of variables for simple weighting to measure the level of environmental literacy and intensity of social norms. The descriptive statistics of these indicators are depicted in Table 2.

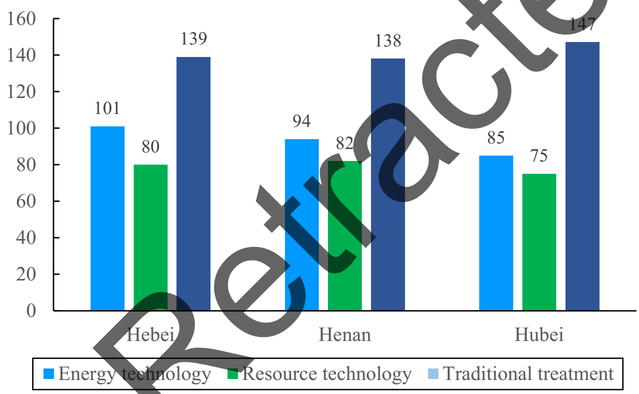

Figure 3.
Statistics of farmers' LMTT adoption in different provinces

Table 2.
Definition and assignment of explanatory variables

Variables	Definition	Assignment
Environmental literacy		
Environmental cognition	Do you think that livestock manure is an important source of carbon emissions?	1 = Strongly disagree – 5 = strongly agree
Environmental skill	Are you proficient in adopting LMTT technologies such as compost fermentation or biogas fermentation?	1 = Very unskilled – 5 = very skilled
Environmental responsibility	Do you think that reducing manure carbon emissions is an individual's social responsibility?	1 = Strongly disagree – 5 = strongly agree
Social norms		
Descriptive social norms	Your relatives, friends or neighbors have adopted the LMTT	1 = very few people – 5 = very many people
Imperative social norms	Your relatives, friends or neighbors think that the LMTT should be adopted	1 = very few people – 5 = very many people

In addition, this article adopts an independent sample *T test* to analyze the difference in the explanatory variables core between adopters and non-adopters to preliminarily judge the relationship between the explanatory variables core (environmental literacy and social norms) and the explained variable (farmers' LMTT adoption). From Table 3, the results show that the *T*-test rejects the null hypothesis and concludes that there are significant differences in environmental literacy and social norms between the adopters and nonadopters. Compared to nonadopters, the overall level of environmental literacy of adopters and the intensity of social norms are higher. Specifically, for energy technology, the mean differences of adopters' environmental skill, environmental responsibility and descriptive social norms are 0.773, 0.506 and 0.426, respectively. Similarly, for resource technology, the mean differences in the environmental skill of adopters' environmental skill, environmental responsibility and imperative social norms are 0.411, 0.330 and 0.489, respectively.

3.4 Control variables

Given that other variables can also influence the adoption of LMTT by farmers and using relevant research by Si, Lu *et al.* (2020), we selected gender, age, education level, net family income, breeding scale, family labor, farmland area, government supervision, government subsidies, technical training and organization participation as control variables. The descriptive statistics of control variables are shown in Table 4.

Table 4 shows that male heads represent 82.16% of the sample and males are still the main decision-makers of the family. About 50.23% of household heads belong to the age group between 41 to 60 years old, and the overall average age of the sample is 46.75 years old. Meanwhile, 67.43% of rural households have an educational level of less than nine years, and most of them belong to primary and middle-level education. The average education level of rural households is 7.80 years. About 77.32% of households have a net income of less than US$10,000, and the overall average income is around US$8,545. Approximately 83.64% of the breeding scale is less than 500, and the breeding scales are mainly composed of free-range (<50 heads) and professional breeding (50–500 heads). Furthermore, 87.41% of households have less than five workers and 94.35% of households have farmland areas of less than 3 hm^2.

3.5 Model specification

3.5.1 Logit and IV-Logit. Given that the adoption of LMTT (energy and resource technologies) by farmers is a discrete binary variable. Therefore, drawing on previous research such as Khan and Habib (2020), the current study used the Logit model to analyze environmental literacy and

Table 3. T-Test for the mean of explained and explanatory variables

Variables	Energy technology adopters	Energy technology non-adopters	Energy technology Mean difference	Resource technology adopters	Resource technology non-adopters	Resource technology Mean difference
Environmental literacy	3.594	3.030	0.564***	3.621	3.190	0.431**
Environmental cognition	3.302	2.890	0.412	3.441	2.890	0.551
Environmental skill	4.373	3.600	0.773**	4.210	3.799	0.411*
Environmental responsibility	3.107	2.601	0.506*	3.211	2.881	0.330***
Social norms	3.812	3.297	0.515***	3.835	3.396	0.439***
Descriptive social norms	3.317	2.891	0.426**	3.281	2.899	0.382
Imperative social norms	4.307	3.703	0.604	4.390	3.901	0.489*

Note: *, **, ***represent the significance level of 10, 5 and 1%, respectively

Variables	Definition and assignment	P.C. (%)	Mean	SD
Gender	1 = Man	82.16	0.822	0.021
	0 = Female	17.84		
Age	18-40 year	30.15	46.753	4.270
	41-60	50.23		
	>61	19.62		
Education level	0-6 year (primary school)	17.25	7.805	1.700
	7-9(Middle school)	50.18		
	10-12(High school)	22.30		
	>12(University)	10.27		
Family net income	<5000 USD	24.15	8545.011	324.152
	5000-10000	53.17		
	10001–20000	15.28		
	>20000	7.4		
Breeding scale	<50 heads	30.29	85.304	7.201
	50–500	53.35		
	>500	16.34		
Family labors	<3 People	27.16	3.703	0.809
	3–5	60.25		
	>5	12.59		
Farmland area	<0.3 hm^2	64.15	1.052	0.041
	0.3–3	30.20		
	>3	5.65		
Government supervision	1 = Yes	40.27	0.403	0.082
	0 = No	59.73		
Government subsidies	1 = Yes	60.16	0.602	0.102
	0 = No	39.84		
Technical training	1 = Yes	70.15	0.702	0.090
	0 = No	29.85		
Organization participation	1 = Yes	42.15	0.422	0.067
	0 = No	57.85		

Table 4. Descriptive statistics of control variables

social norms on the adoption of farmers' energy and resource technologies, respectively. Compared to the Probit model, also widely used for microeconomic econometric analysis, the Logit model does not require the survey data to completely obey the normal distribution and has the consistency of the estimated results with the maximum utility theory (Babiker *et al.*, 2021). The Logit model formula is as follows:

$$Ln\left(\frac{p}{1-p}\right) = \beta_0 + \sum_{i=1}^{n}\beta_i x_i + \mu$$

$$\frac{p}{1-p} = \exp\left(\beta_0 + \sum_{i=1}^{n}\beta_i x_i\right) \tag{1}$$

$$p = F\left(\beta_0 + \sum_{i=1}^{n}\beta_i x_i\right) = \frac{1}{1+\exp\left[-\left(\beta_0 + \sum_{i=1}^{n}\beta_i x_i\right)\right]}$$

$$Prob(decision = 1|literacy, norm, X) = \varphi(\alpha + \beta_1 literacy + \beta_2 norm + X\theta + \varepsilon) \tag{2}$$

In formula (1), where p represents the probability (0–1) of farmers' LMTT adoption. β_0 is regression intercept (constant term). x_i is the influencing factors of the adoption of LMTT by farmers, including *literacy, norm and X.* β_i is the regression coefficient of the *i*-th influencing factor. μ is random interference. In formula (2) the *decision* represents the decision of farmers to adopt energy or resource technologies. If energy or resource technologies are adopted, then the assigned value is 1. Otherwise, it shows that farmers have not adopted energy or resource technologies. Literacy means environmental literacy (environmental cognition, skill and responsibility). The *norm* signifies social norms (descriptive and imperative social norms). The X are the control variables. β_1, β_2 and θ are the estimated vectors of the environmental literacy, social norms and control variables estimated by the regression coefficients, respectively. ε represents the independent and identically distributed random error term and $\varphi(\cdot)$ is the probability function of the logistic distribution.

Previous research has confirmed a reverse causal relationship between the level of agricultural skills and the adoption of farmers' technologies (Xue *et al.*, 2021). As the intensity of the adoption of LMTT by farmers increases, the environmental skill of farmers also tends to increase synchronously. Therefore, there may also be a reverse causal relationship between environmental skill and the adoption of LMTT by farmers, which further results in an endogenous problem and ultimately leads to bias in the logit model estimation results. Furthermore, omitted control variables can affect both the core explanatory variables and explained variables, thus exacerbating the endogeneity issues. Therefore, the current study chooses variables such as "the nearest distance between barn and livestock department" as an instrumental variable and applies the IV-logit model to amend the endogeneity issue. The main reasons for this instrumental variable chosen are as follows: On the one hand, the adoption of LMTT by farmers is not subject to the imperative restrictions of the livestock department, and the adoption of LMTT depends on the wishes of farmers. Consequently, "the nearest distance between the barn and the livestock department" is not directly related to the adoption of LMTT by farmers, so the variable is considered as exogenous variables. On the other hand, the closer the pig barn is to the livestock department, the more convenient it is to accept the livestock department's environmental technical guidance. In this vein, farmers have higher environmental skill, which meets the correlation between instrumental variables and endogenous variables. Thus, "the nearest distance between the barn and livestock department" is regarded an appropriate instrumental variable in the current study.

3.5.2 Moderating effect model. If the influence of the explanatory variable X on the explained variable Y changes with the change of the third variable M, then the variable M will play a moderating role in the relationship between X and Y (Weise *et al.*, 2020). When both X and Y are continuous variables, the interaction term of X and Y can be introduced into the model to test the moderating effect. If the interaction term is significant, the variable M will have a significant moderating impact (Sánchez-Infante Hernández *et al.*, 2020). This paper introduces the interactive items of environmental cognition, environmental skill, environmental responsibility and social norm, respectively, to test the possible moderating effects of social norms on the impact of environmental literacy on the adoption of LMTT by farmers. The specific model is as follows:

$$Prob(decision = 1|literacy, norm, X) = \varphi(\alpha + \beta_1 literacy + \beta_2 norm + \beta_3 norm \times literacy + X\theta + \varepsilon) \tag{3}$$

The literacy × norm represents interaction terms, and β_3 is the estimated value vector of the interaction term. The connotation of other variables is the same as formula (1).

4. Results and discussion

4.1 Model fitting results

As shown in Models 1 and 4 in Table 5, we used the logit model to analyze the influence of environmental literacy and social norms on the adoption of energy and resource technologies by farmers. Furthermore, we explored the impact of different dimensions of environmental literacy and social norms on explained variables, as shown in Models 2 and 5. The results in Table 5 show that the LRχ^2values of equations (1), (2), (4) and (5) at 1% significance level are 45.27, 44.05, 45.29 and 44.01, respectively, indicating that models fit the data.

To fix the endogeneity issue, we applied the IV-Logit model, as shown in Table 5. The findings show that the Waldχ^2 values of equations (3) and (6) at a 5% significance level are 40.28 and 41.06, respectively. The Durbin–Wu–Hausman (DWH) test values are 6.27 and 6.04, respectively, which are highly significant at a 1% level of significance, indicating that the model has an endogenous issue. In this case, using a conventional regression model may lead to biased results, so employing IV-Logit estimation is appropriate in the current study.

The study also examined the effectiveness of the instrumental variable "the nearest distance between the pig barn and the livestock department." Analogous to the study of Xu *et al.* (2018), the results show that the F values in the first stage of equations (3) and (6) are 12.05 and 13.90 (the critical value F = 10), respectively, concluding that the endogenous variable and instrumental variable are highly correlated, so there is no weak instrumental variable. In addition, we conducted a multicollinearity test, and the maximum and minimum VIF values were 2.75 and 0.67 (the critical value F = 10), respectively. So there were no multicollinearity issues among variables.

4.2 The impact of environmental literacy and social norms on farmers' low-carbon manure treatment technology adoption

The estimation results of Models 1 and 4 show that environmental literacy significantly influences the adoption of energy and resource technologies by farmers. *H1* is confirmed. The marginal effect is 0.090 and 0.066, which means that if the level of environmental literacy increases by 1 unit, the probability of farmers' energy and resource technologies will increase by 9.0% and 6.6%, respectively. The results are consistent with the empirical findings of Adama *et al.* (2018) and Xue *et al.* (2021), who also showed that environmental literacy is beneficial in promoting the adoption of green technologies by farmers.

The improvement of farmers' environmental literacy indicates that farmers have a clear understanding of environmental issues, hold a stronger will to adopt green production technologies, and show a more responsible attitude towards environmental protection strategies (Li *et al.*, 2020). In particular, environmental literacy can inspire farmers to adopt LMTT by strengthening environmental cognition. Farmers can recognize the importance of sustainable production by switching to low carbon production methods (Faisal *et al.*, 2021; He *et al.*, 2016). Furthermore, environmental literacy encourages farmers to actively adopt LMTT technology by broadening technology acquisition channels, improving technical operating standards and raising subsidy standards (Si, Wang, *et al.*, 2020). Further, environmental responsibility is an essential driving factor for farmers to transform from economic rationality to ecological rationality (Bakker *et al.*, 2021; Graddy-Lovelace, 2020). In practice, despite the long payback period of the LMTT investment, environmental responsibility can encourage farmers to increase the investment in the adoption of LMTT

Table 5.
The impact of environmental literacy and social norms on farmers' LMTT adoption

Variables	Energy technology Logit Model 1	Logit Model 2	IV-Logit Model 3	Resource technology Logit Model 4	Logit Model 5	IV-Logit Model 6
Environmental literacy	0.090*** (0.032)	–	–	0.066** (0.031)	–	–
Environmental cognition	–	0.047 (0.031)	0.046 (0.031)	–	0.011 (0.007)	0.010 (0.008)
Environmental skill	–	0.095** (0.043)	0.033** (0.014)	–	0.063* (0.034)	0.032* (0.017)
Environmental responsibility	–	0.032*** (0.010)	0.030*** (0.011)	–	0.053* (0.028)	0.051* (0.027)
Social norms	0.061** (0.027)	–	–	0.073** (0.036)	–	–
Descriptive social norms	–	0.046 (0.060)	0.040 (0.059)	–	0.063 (0.072)	0.061 (0.073)
Imperative social norms	–	0.028*** (0.011)	0.029*** (0.009)	–	0.086*** (0.021)	0.083*** (0.025)
Gender	0.018 (0.021)	0.017 (0.022)	0.015 (0.021)	0.013 (0.031)	0.012 (0.031)	0.017 (0.032)
Age	0.060 (0.073)	0.046 (0.053)	0.057 (0.061)	0.021 (0.043)	0.032 (0.054)	0.0302 (0.051)
Education level	0.081* (0.044)	0.084* (0.045)	0.082* (0.043)	0.048** (0.023)	0.041** (0.018)	0.058** (0.025)
Family net income	0.063*** (0.022)	0.062*** (0.024)	0.061*** (0.022)	0.051* (0.027)	0.051* (0.027)	0.059* (0.031)
Breeding scale	0.102*** (0.035)	0.091*** (0.031)	0.093*** (0.029)	0.121*** (0.039)	0.111*** (0.039)	0.101*** (0.028)
Family labors	0.030 (0.041)	0.037 (0.041)	0.041 (0.044)	0.052 (0.072)	0.051 (0.073)	0.051 (0.071)
Farmland area	0.032 (0.041)	0.030 (0.041)	0.053 (0.049)	0.034 (0.031)	0.031 (0.047)	0.031 (0.041)
Government supervision	0.011 (0.008)	0.011 (0.008)	0.011 (0.008)	0.021 (0.041)	0.019 (0.038)	0.020 (0.040)
Government subsidies	0.053** (0.023)	0.038** (0.018)	0.021** (0.008)	0.015* (0.008)	0.020* (0.011)	0.019* (0.011)
Technical training	0.021 (0.146)	0.011 (0.008)	0.011 (0.092)	0.031 (0.027)	0.028 (0.031)	0.019 (0.275)
Organization participation	0.061*** (0.022)	0.071*** (0.025)	0.071*** (0.017)	0.067*** (0.025)	0.071*** (0.021)	0.069*** (0.022)
LRχ^2 Test	45.270***	44.052***	–	45.291***	44.008***	–
p-value	0.000	0.000	–	0.000	0.000	–
Wald χ^2 Test	–	–	40.276**	–	41.061**	–
F value in the first stage	–	–	12.051***	–	–	13.903***
DWH Test			6.27***	–	–	6.04***
Sample size	941	941	941	941	941	941

Notes: *, **, ***represent the significance level of 10, 5 and 1%, respectively. The marginal effect is reported in the table and the robust standard error is shown in parentheses

(Varma *et al.*, 2021a). Finally, our research further promotes the development of traditional agricultural economic management theories such as government support and organization participation, and believes that environmental literacy can improve the endogenous motivation for farmers' technology adoption and has become a foundation for playing a role in the external environment, such as government and organizational support (N'souvi *et al.*, 2021; Qi *et al.*, 2021).

In social norms, the findings show a positive and significant influence on farmers' LMTT adoption. *H2* is confirmed. The marginal effect is 0.061 and 0.073, which reveals that if the intensity of social norms increases by 1 unit, the probability of farmers' energy and resource technology adoption will increase by 6.1% and 7.3%, respectively. Our findings are consistent with the empirical results of He *et al.* (2017) and Zhong and Huang (2017). They showed that farmers in developing countries generally have a strong face concept, an inducing factor in the formation of social norms, which has been a critical determinant in the adoption of green technologies by farmers. Moreover, some scholars argued that the face concept is a manifestation of mutual benefit between individuals, the so-called "human relationship," and it also has the meaning of social evaluation, prestige and status (Dong *et al.*, 2018). Furthermore, other scholars explored the influence of social norms on the adoption of green technologies by farmers from the perspective of peer effect and social pressure (Adnan *et al.*, 2019; Bansal *et al.*, 2021). Farmers usually follow the behavior of the same group to avoid collective condemnation and alleviate social pressure due to deviation of behavior, maintain social relations, maintain a sense of communal belonging and improve understanding of honor (Cai *et al.*, 2019; Dan and Kong, 2015). Consequently, our research pioneered a new exploration of the promotion mechanism of social norms influencing farmers' technology adoption.

The estimation results of Models 2 and 4 show that environmental cognition has not shown significant results for the adoption of LMTT adoption; hence, *H1a* is falsified. Environmental skill and responsibility positively and significantly influence the adoption of agricultural energy and resource technologies, thus confirming *H1b* and *H1c*. Specifically, the marginal effect of environmental skill and environmental responsibility on farmers adopting energy technology is 0.095 and 0.032, which means that if the level of environmental skill and environmental responsibility increases by 1 unit, the probability of farmers adopting energy technology will increase by 9.5% and 3.2%. Similarly, the marginal effect of environmental skill and environmental responsibility on farmers adopting resource technology is 0.063 and 0.053, revealing that the probability of adopting resource technology will increase by 6.3% and 5.3%, respectively. These findings are supported by Li *et al.* (2020) and Musafiri *et al.* (2022). They also believed that low-carbon production skills and environmental responsibility for carbon emission reduction have beneficial effects on farmers' adoption of low-carbon agricultural technologies. Biogas fermentation requires excellent conditions to control temperature and moisture, and compost fermentation requires precise settings of fermentation tanks and storage time (Zahedi *et al.*, 2022). Technology acquisition has become a bottleneck factor in promoting the adoption of low-carbon agricultural technology by farmers (Damalas and Koutroubas, 2018). As for environmental responsibility, livestock manure carbon emission has a negative external effect, and economic rationality is prone to produce the "tragedy of the commons". A strong sense of environmental responsibility tends to drive farmers to make decisions about the adoption of LMTT from the perspective of ecological and social rationality (Tadaki *et al.*, 2015; Zhang, Li, *et al.*, 2020).

Moving toward the imperative social norms, the results show that it exerts a positive and significant influence on farmers' LMTT adoption. However, descriptive social norms have no significant impact on farmers' LMTT adoption. Therefore, *H2b* is confirmed and *H2a* falsified. Specifically, the marginal effect of imperative social norms on the adoption of LMTT by farmers is 0.028 and 0.086, which means that if the intensity of imperative social norms increases by 1 unit, the adoption of energy and resource technology by farmers will increase by 2.8% and 8.6%, respectively. When most farmers have established group norms such as "they should adopt LMTT," and if some farmers do not adopt the LMTT, they will be under tremendous social pressure. Therefore, farmers will consider the risk of penalties from public opinion when making decisions about the adoption of green technologies (Dong and Lian, 2021; Robinson *et al.*, 2020). When environmental property rights are difficult to define, imperative social norms reduce the possibility of farmers' "free-rider effect," and the externality of social public opinion supervision to a certain extent can be internalized into individual behavior costs. However, descriptive social norms are not significant, indicating that when the rate of adoption of LMTT by farmers is low, they are less affected by the behavioral decisions of other farmers, finally eliminating the economic "peer effect" (Nguyen, *et al.*, 2020).

Compared to Models 2 and 5, the estimated results of Models 3 and 6 show that the marginal effect of environmental skill is reduced, indicating that if the simultaneity biases are not dealt with, the impact of environmental skill on the adoption of LMTT by farmers can be overestimated. Specifically, the effects of environmental skill on the adoption of LMTT (energy and resource technologies) by farmers are stronger than environmental responsibility. The marginal effect of environmental skill on the adoption of energy technology by farmers is 0.033 and 0.030, which means that if the level of environmental skill and responsibility increases by 1 unit, the probability of adoption of energy technology by farmers will increase by 3.3% and 3.0%, respectively. The marginal effect of environmental skill on the adoption of farm resource technology is 0.032 and 0.051, revealing that the probability of the adoption of farm resource technology will increase by 3.2% and 5.1%, respectively. Additionally, imperative social norms have a significant influence on farmers' LMTT adoption. If the intensity of imperative social norms increases by 1 unit, the rate of adoption of farmers' energy and resource technologies will increase by 2.9% and 8.3%, respectively.

For control variables, the results are significant for some variables. For example, the effect of education level on the adoption of LMTT by farmers is 0.082 and 0.058, which shows that if education level increases one year, the probability of the adoption of energy and resource technologies by farmers will increase by 8.2% and 5.8%. Good education is an essential incentive for farmers to opt for green production behavior (Adama *et al.*, 2018). The effect of the breeding scale on the adoption of LMTT by farmers is 0.093 and 0.101, which means that if the breeding scale increases by one head, the probability of farmers adopting energy and resource technologies will increase by 9.3% and 10.1%, respectively, which is consistent with the empirical research of Hou and Hou (2019), who showed that the larger the breeding scale, the more farmers are willing to adopt clean production technologies. Farmers with higher family net income and government subsidies are more inclined to adopt LMTT. Consistent with the research results of Yuan and Zhang (2020), the cost reduction and incentives effects of economic capital positively affect the farmer's technology investment and adoption. Furthermore, the effect of organizational participation on the adoption of LMTT by farmers is 0.071 and 0.069, which reveals that if organizational participation increases by 1 unit, the probability of adoption of energy and resource technologies by farmers will increase by 7.1% and 6.9%, respectively. These findings confirm the view of Huang *et al.* (2020), who argued that organizational participation can provide technical assistance, product sales and standard guidance to promote the adoption of green production technology by farmers.

4.3 The moderating effect of social norms in environmental literacy affecting farmers' low-carbon manure treatment technology adoption

This article introduces the interaction terms of environmental literacy and social norms in Models 1 and 4 to further analyze the moderating effect of social norms in environmental literacy that influences the adoption of LMTT by farmers and finally obtain the estimated results of Models 7 and 9. For Models 3 and 5, the interactive terms of environmental cognition and social norms, environmental skill and social norms and environmental responsibility and social norms are introduced, and Models 8 and 10 are obtained, respectively, as shown in Table 6.

From Models 7 and 9, the interaction terms of environmental literacy and social norms are significant at the significance level of 10% and 5%, respectively, indicating that social norms have a crucial determinant of environmental literacy that affects the adoption of energy and resource technologies by farmers. Furthermore, the moderating effect of social norms on environmental literacy that influences farmers' resource technology is more substantial, and therefore *H3* is confirmed. The results are consistent with Daxini *et al.* (2019), who believed that social norms as an informal system could improve the impact of environmental skill and environmental responsibility on the adoption of green technologies by farmers. Just as Wang *et al.* (2017) also confirmed the moderating role of social norms in environmental literacy affecting farmers' fertilizers and pesticide reduction behavior. The higher the intensity of social norms, the higher the environmental literacy of farmers and ultimately leads to a better farmer enthusiasm for adopting green technologies.

In Models 8 and 10, the interaction terms of environmental skill and social norms and the interaction terms of environmental responsibility and social norms are significant, indicating that social norms also play an important moderating role. Meanwhile, compared to energy technology, social norms exert a more robust regulatory effect on environmental literacy, affecting the adoption of resource technologies by farmers. Therefore, *H3a* is falsified, *H3b* and *H3c* are confirmed. It reflects that social norms can effectively convey LMTT information to farmers through social networks, improving farmers' sense of

	Energy technology		Resource technology	
	Logit	IV-Logit	Logit	IV-Logit
Variables	Model 7	Model 8	Model 9	Model 10
Environmental literacy	0.072** (0.033)	–	0.046** (0.020)	–
Environmental cognition	–	0.038 (0.029)		0.012 (0.007)
Environmental skill	–	0.030** (0.014)	–	0.033* (0.018)
Environmental responsibility	–	0.036*** (0.012)	–	0.071* (0.037)
Social norms	0.069** (0.030)	–	0.073** (0.032)	–
Environmental literacy* social norms	0.102* (0.055)	–	0.123** (0.050)	–
Environmental cognition* social norms	–	0.038 (0.025)	–	0.008 (0.011)
Environmental skill * social norms	–	0.053** (0.024)	–	0.072** (0.033)
Environmental responsibility * social norms	–	0.073* (0.040)	–	0.079*** (0.022)
Control variables	Controlled			

Notes: *, **, ***represent the significance level of 10, 5 and 1%, respectively. The marginal effect is reported in the table, and the robust standard error is shown in parentheses

Table 6. Moderating effects of social norms

responsibility and promoting farmers' awareness in adopting the LMTT (Ardoin *et al.*, 2020; Germar and Mojzisch, 2019). Our research has further enriched traditional farmer behavior theory, just as Govindharaj *et al.* (2021) hold that farmers' behaviors are the result of the combined effect of internal and external factors, while our research further explores how exogenous variables, such as social norms, exert behavioral restraints or guidance effects on environmental literacy, e.g. endogenous variables.

4.4 Robustness test

Previous studies on robustness test methods consisted mainly of model replacement, variable replacement and sample re-extraction (Sarma, 2022; Wens *et al.*, 2021). Thus, we also employ the Probit and IV-probit models to test the robustness of the model estimation results by substituting the core explanatory variable 'environmental literacy'. Specifically, compared with the Logit model, the Probit model assumes that the original data follow a normal distribution rather than a logistic distribution, and the model application conditions are stricter. Additionally, we use "do you think the environmental pollution of manure is serious?" to represent environmental cognition, "how many times do you receive LMTT training per year?" to characterize environmental skill, and "are you willing to improve the ecological environment in the village?" to describe environmental responsibility. The model estimation results in Table 7 report that compared with the Logit and IV-Logit models estimation results in Table 5, the effects of the core explanatory variables did not change significantly. Hence, the benchmark model regression results show good robustness.

5. Conclusions and policy implications

Climate change has exerted a huge influence on humans and ecosystems, and the climate affects that it causes are increasing sharply. The livestock sector is an essential contributor to global carbon emissions. As a significant livestock breeding country globally, increasing the intensity of farmers' LMTT adoption in China is conducive to cope with the rising world's carbon emission and global climate damage. Unfortunately, the acceptance and adoption rate of farmers' LMTT is still relatively low. Furthermore, existing research has not theoretically analyzed the adoption of LMTT by farmers from the perspectives of behavioral economics and management. Consequently, we introduced environmental literacy and social norms into the analysis framework of farmers' LMTT adoption to identify critical driving factors in improving the probability of farmers' LMTT adoption

Table 7. Results of robustness test

Variables	Energy technology Logit Model 11	Energy technology IV-Logit Model 12	Resource technology Logit Model 13	Resource technology IV-Logit Model 14
Environmental literacy	0.086*** (0.027)	–	0.064** (0.032)	–
Environmental cognition	–	0.031 (0.042)	–	0.016 (0.013)
Environmental skill	–	0.031** (0.015)	–	0.035* (0.018)
Environmental responsibility	–	0.037*** (0.012)	–	0.042* (0.022)
Social norms	0.068** (0.028)	–	0.079** (0.035)	–
Descriptive social norms	–	0.049 (0.035)	–	0.051 (0.072)
Imperative social norms	–	0.032*** (0.011)	–	0.085*** (0.024)
Control variables	Controlled			

Notes: *, **, ***represent the significance level of 10, 5 and 1%, respectively. The marginal effect is reported in the table, and the robust standard error is shown in parentheses and ultimately achieving carbon peak and carbon neutrality. Besides, the main theoretical contributions of this study are two aspects: On the one hand, as the adoption of farmers' LMTT has typical public goods attributes, this research breaks through the original theory of planning behavior and introduces environmental literacy and social norms into the analysis framework of the adoption of farmers' LMTT, thus enriching the theoretical connotations of traditional agricultural economics. On the other hand, this paper abandons the judgment of the rational assumption of the individual and analyzes the bounded rationality, such as ecological and social rationalities concerning the effects of environmental literacy and social norms, which will enrich the research limits of agricultural technology theory.

The overall findings show that environmental literacy and social norms positively and significantly influence farmers' LMTT adoption. Specifically, the effects of environmental literacy on the adoption of LMTT by farmers are mainly contributed by environmental skills and environmental responsibility. And the improvement of social norms in the adoption of LMTT by farmers is primarily due to the leading role of imperative social norms. Additionally, after addressing the simultaneity biases caused by the reverse effect between environmental skill and the adoption of LMTT by farmers, the results reveal that the effect of environmental skill is weakened. Furthermore, social norms are found to have moderating effects on environmental literacy that influence the adoption of farmers' LMTT. Compared with energy technology, social norms have a more robust regulatory effect in environmental literacy that affects the adoption of agricultural resource technology.

In essence, based on the empirical findings, the current study proposes some policy implications. First, the government should increase farmers' cognition and their confidence in LMTT adoption. In this regard, the government should use electronic and print media to publicize the application, operation and implementation of the LMTT. Second, the government should establish social organizations to provide technical assistance and support farmers in improving their knowledge about the LMTT. Third, the government should strengthen environmental education for farmers, especially in response to environmental issues caused by livestock manure, so that farmers can forecast the consequences of environmental hazards and enhance their sense of environmental responsibility. Fourth, the government should increase the subsidy standard according to the adopted area of the LMTT and give full play to the leveraging effect of fiscal policy. Finally, the government should encourage the construction of village regulations and folk agreements, including environmental protection initiatives and environmental damage penalties, which can compensate for the restraining and leading role of formal rules such as laws and regulations.

These research conclusions can provide an empirical and useful experience for other countries, especially developing countries. Our research also has some shortcomings: first, the LMTT in the current study includes energy and resource technologies, while the cost and benefit of these technologies are different. Therefore, it is necessary to further study how the cost-benefit relationship affects the adoption of LMTT by farmers. Second, there are apparent differences in the economic and social structures embedded in farmers of different regions and scales, which determines that the effects and transmission mechanism of environmental literacy and social norms on the adoption of LMTT by farmers can be heterogeneous. Thus, future research should consider the heterogeneity of breeding scale, and differentiated incentive or restrictive policies for the government should be proposed. Third, due to the lack of related data, the current study did not consider the impact of natural factors such as topography, temperature and humidity on the adoption of LMTT by farmers. Missing variables may cause endogenous issues. Of course, these shortcomings also provide exciting avenues for future research.

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