

Article

The Impact of Training on Beef Cattle Farmers' Installation of Biogas Digesters

Qian Li ¹, Jingjing Wang ², Xiaoyang Wang ² and Yubin Wang ^{3,*}¹ College of Economics, Beijing Technology and Business University, Beijing 100048, China; liqian2016@cau.edu.cn² Department of Economics, University of New Mexico, Albuquerque, NM 87131, USA; wangj@unm.edu (J.W.); xiaoyangwang@unm.edu (X.W.)³ College of Economics and Management, China Agricultural University, Beijing 100083, China

* Correspondence: wyb@cau.edu.cn

Abstract: Anaerobic digestion is one of the leading ways to manage livestock manure for energy production and move towards the target of carbon neutrality in the agricultural sector. Based on field survey data from China, a binary probit model and the propensity score matching method are employed to empirically examine the impact of agricultural training on livestock farmers' installation of biogas digesters to manage livestock manure. The survey results show that beef cattle farmers in our study area are reluctant to install biogas digesters and the actual installation ratio of farmers is much lower than that that is willing to install. On the contrary, the beef cattle farmers are enthusiastic to participate in training (e.g., policy-oriented, technology-oriented, and field-based) related to sustainable farming practices. Regression results suggest that training can effectively promote the installation of biogas digesters, and with the increase of training intensity, the probability to install biogas digesters increases. We further find three other factors that affect farmers' installation of biogas digesters: the education level of a farmer, which is one of the most important factors positively affecting the installation of biogas digesters; longer farming experience of a farmer, which can significantly promote biogas digester installation; and the farther away a farm is from town/urban centers, which means the more likely it is that the farmer will install biogas digesters. Policy implications are discussed.

Keywords: beef cattle; biogas digesters; manure management; training

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1. Introduction

Anaerobic digestion is increasingly used to generate biogas from livestock manure worldwide. It has been shown to create significant economic and environmental benefits [1–3], especially in greenhouse gases emission reduction. Anthropogenic activities that directly or indirectly release methane into the atmosphere are responsible for as much as a third of the global warming occurring at the present time [4]. Livestock farming is one of the leading anthropogenic sources of greenhouse gases emission. The feasibility of mass anaerobic digestion of livestock manure for biogas production has therefore attracted increasing attention among policymakers and researchers. Research has been performed on the cost-benefit analysis of biogas production from livestock manure from the standpoint of livestock farmers [5–8]. Whereas some studies find biogas production from livestock manure to be beneficial, others find opposite results. For example, Kiratikarnkul [9] conducted a cost-benefit analysis of alternative manure disposal methods in the hog sector of Thailand and found that biogas production actually provides fewer benefits than some of the other disposal methods. Ribeiro et al. [10] also came to a similar conclusion that energy production from poultry manure does not demonstrate economic viability. From the perspective of energy production, there are also some other alternative manure management techniques, including co-combustion and gasification [11,12], which have been shown to be feasible

and promising. This also indirectly supports the feasibility of biogas production from livestock manure. Although there is no consensus in the literature, examples exist that livestock farmers around the world are installing anaerobic digesters to treat manure and produce biogas. It is thus important to understand what factors lead livestock farmers to install such biogas digesters.

With the increasing size of livestock farms, the volume of livestock manure also increases significantly with a steadily growing trend. According to FAO [13], the global production of livestock manure (in terms of nitrogen content) increased from 73.9 million tons in 1961 to 127.6 million tons in 2019, with an average annual growth rate of 0.95%. Improper management of manure from farms can produce adverse environmental and health effects [14,15]. The increased concentration of livestock farms has further exacerbated the risk of environmental pollution and health damage [16–18]. From the perspective of manure sources, beef cattle are the main source of livestock manure. In 2019, the global production of beef cattle manure was 46.3 million tons, accounting for 31.9% of total livestock manure [13]. From a regional perspective, Asia produces the largest amount of livestock manure, accounting for 37.1% of the global manure production in 2019, most of which is from China. In 2019, China's livestock manure reached 12.4 million tons, ranking first in the world [13]. China is facing a significant challenge in sustainable manure management [19,20]. Therefore, using China as a case study to explore the management of livestock manure, especially beef cattle manure, is of great representativeness.

Biogas production from livestock manure through anaerobic digestion is one of the most effective greenhouse gas mitigation options for manure management [21]. The evaluation of energy potential is also one of the manifestations of the feasibility of biogas production. Previous studies focus on a certain region (e.g., Turkey, Iran and China) or a certain animal species (e.g., poultry, hog, goat, and dairy cattle) to evaluate the biogas potential of livestock manure [1,22–24]. Ayhan et al. [25] conduct laboratory-scale experiments to evaluate biogas production from the co-digestion of dairy cattle manure and maize silage and show that co-digestion has positive effects on biogas production and the methane content of biogas. Other studies comprehensively and systematically investigate the potential economic and environmental feasibility of biogas production from livestock manure. For example, Manesh et al. [26] conduct a feasibility study on the energy, economic and environmental impacts of biogas production from poultry manure in Iran and find low use of Iran's capacity for biogas production despite its high potential.

There are different ways to manage livestock manure. The common techniques include land application, processing it into organic fertilizer, processing it into substrate, and anaerobic digestion [27]. Among these techniques, the land application of manure is the most widely used eco-friendly and traditional approach [28,29]; however, it is limited by the availability of cropland [30–32], especially in recent years. At present, the rate of manure applied to cropland is only 21.3% in 2019 [13]. With the separation of crop and livestock farming, the land application of manure is becoming more and more difficult, and disadvantages of this method are gradually being exposed in the form of risks of air and water contamination [33–35]. On the other hand, anaerobic digestion is a clean and efficient way to treat livestock manure. It provides a renewable energy source that is clean and can easily replace firewood or fossil fuels [26]. Thus, biogas production from livestock manure via anaerobic digesters (i.e., biogas digesters) is becoming popular around the world and is considered by governments for both sustainability and energy security purposes. Various measures have been introduced to promote the installation of biogas digesters, including training programs targeting livestock farmers. Whether such training programs motivate livestock farmers to install biogas digesters remains to be examined.

Training is a form of communication intended for the purpose of developing skills, modifying behavior, and increasing competence. It is generally targeted at a specific group and focuses on a specific topic. Training related to sustainable farming practices is generally provided directly by government agencies or third-party training vendors hired by the agencies. For example, in the U.S., agricultural extension centers provide various training

to local farmers in the form of classes, workshops and field trips. In China, technical experts are often hired by the government to carry out training in classrooms [36]. Therefore, training related to sustainable farming practices has a strong attribute of public goods.

There are three major types of agricultural training programs: policy-oriented training that focuses on providing policy information, technology-oriented training that focuses on providing technical guidance, and field-based training that focuses on the experiential learning experience. Policy-oriented training is a common type of training. This training can improve farmers' awareness of policies related to sustainable farming practices, facilitate the timely and comprehensive understanding and familiarity with relevant policies, and be able to engage in policy-related investments. Opportunities are provided for participants to obtain financial support related to relevant policies, such as subsidies for large-scale farming, subsidies for standardized farm construction, and subsidies for biogas digester installation. Therefore, policy-oriented training is conducive to livestock farmers' installation of biogas digesters.

Technology-oriented training is mainly provided by technical experts. The goal of this type of training is to explain the relevant technology, break the promotion obstacles of new technologies through knowledge dissemination, and improve the technical ability or management level of participants who adopt the technology with new equipment and/or facilities, as well as the operation and maintenance of the equipment and facilities [37]. Participants can obtain timely technical support through both training and building relationships with relevant technical staff, or even long-term cooperation. Therefore, in the context of sustainable farming practices, technology-oriented training is also conducive to livestock farmers' installation of a biogas digester.

Field-based training, also known in some countries as on-the-spot training, is another common type of training which provides experiential, field-based learning activities [38]. In the agricultural sector, field-based training is generally held on farms with state-of-the-art sustainable farming practices. Through on-site visits and demonstrations, farmers participating in the training better understand the environment-friendly management practices and resulting effects. This can encourage the participants to adopt the same or similar management practices, such as installing biogas digesters to recycle manure.

In addition to the direct effects of training on participants, there are also indirect positive impacts via peer effects. Studies show that agricultural training can promote communication and information sharing among farmers [39] by influencing each other's farming decisions through an experience exchange where there are social effects between individuals [40,41]. Li et al. [42] demonstrated that knowledge exchanges and transfers through peers and training show a significant and positive impact on rice farmers' adoption of agricultural low-carbon technologies. In addition, for the installation of biogas digesters, in order to match the capacity of biogas digesters with the farming scale, some farmers cooperate with one another to install biogas digesters to jointly treat or assist in the treatment of livestock manure. In short, all kinds of training can change farmers' cognition to varying degrees [43], thereby affecting their decision-making.

There is extensive literature on the effectiveness of agricultural training programs. From the perspective of outcomes, existing studies show that agricultural training can contribute to higher agricultural productivity [44], higher rural income and better livelihoods [45], and sustainable food security [37]. From the perspective of behavior-altering, agricultural training can affect the behavior of trainees. For example, training has been shown to affect the adoption of conservation tillage [36], agrochemicals selection and application [46], the adoption of improved cultivation practices [47], soil fertility management practices [48], and climate change adaptation strategies [42]. Despite the potential benefits of the agricultural training programs, there are doubts about the effectiveness of such training due to poor training practices [39], a lack of integrative agricultural communication [49], or the inability to meet the actual education and training needs of farmers [37,50]. In particular, the effectiveness of training programs on biogas digester installation in the livestock sector has not been explored in previous research.

This study uses field survey data of beef cattle farmers in China to empirically examine the effectiveness of farmer training on beef cattle farms' installation of biogas digesters. We hypothesize that training is effective in promoting livestock farmers to install biogas digesters to manage manure and that the more intense the training, the higher the effectiveness. The hypotheses are tested through the statistical modeling of primary farm-level survey data from a leading beef cattle production region in China. There are two major contributions of this study. First, existing studies on the installation of biogas digesters on livestock farms mainly employs case-study approaches with a technical perspective. This study fills a gap in the literature by looking into the behavioral aspect. Second, to our knowledge, this is the first study using primary farm-level survey data from a leading livestock production region to empirically examine the effectiveness of agricultural training on biogas facility installation.

2. Materials and Methods

2.1. Model

The response variable in this study is whether a beef cattle farmer has installed biogas digesters, which is a binary choice variable. Following the literature [51–53], a binary probit model is constructed. The specific expressions of the model are shown in Equations (1) and (2).

Here the probability of a farmer installing biogas digesters is:

$$P(\text{Biogas}_i = 1) = \Phi(\alpha + \beta \text{Training}_i + \sum \lambda_k \text{Control}_{ik} + \varepsilon_i) \quad (1)$$

while the probability of a farmer not installing biogas digesters is:

$$P(\text{Biogas}_i = 0) = 1 - \Phi(\alpha + \beta \text{Training}_i + \sum \lambda_k \text{Control}_{ik} + \varepsilon_i) \quad (2)$$

where i denotes the i th observation of the sample and Biogas_i denotes the action of farmer i in biogas digesters installation. If a farmer has installed a biogas digester, Biogas_i value is 1; otherwise, it is assigned 0. $P(\text{Biogas}_i = 1)$ represents the probability of farmer i installing biogas digesters, and $P(\text{Biogas}_i = 0)$ represents the probability of farmer i not installing biogas digesters. Training_i is the core explanatory variable of agricultural training. Control_{ik} is a set of control variables consists of k variables. α is the constant term, and ε_i is the residual term. Assuming a normal cumulative distribution function $\Phi(\cdot)$, the coefficients β and λ_k are parameters to be estimated from regression.

The marginal effect of training on the probability of a farmer installing biogas digesters is as follows:

$$\frac{\partial P(\text{Biogas}_i = 1)}{\partial \text{Training}_i} = \varphi(\alpha + \beta \text{Training}_i + \sum \lambda_k \text{Control}_{ik} + \varepsilon_i) \beta \quad (3)$$

In Equation (3), $\varphi(\cdot)$ represents the conditional probability of the normal distribution function $\Phi(\cdot)$. $\frac{\partial P(\text{Biogas}_i=1)}{\partial \text{Training}_i}$ is the marginal probability for a farmer to install biogas digesters after attending training programs. When Training_i takes binary values of 1 or 0 to represent received training or not, the marginal impact of training on the probability reduces to $P(\text{Biogas}_i = 1 | \text{Training}_i = 1) = \Phi(\alpha + \beta + \sum \lambda_k \text{Control}_{ik}) - \Phi(\alpha + \sum \lambda_k \text{Control}_{ik})$.

2.2. Data

2.2.1. Field Survey and Sample

The data used in this study is obtained from a field survey conducted in 2018 by the research group in Henan Province, China's main beef cattle producing province. With reference to the relevant literature, and through expert consultation and previous field investigation, the first draft of the survey questionnaire was designed. A pre-survey was carried out first, and then the survey questionnaires were revised and improved based on pre-survey results (see Appendix A). The formal survey was then carried out. The survey

was conducted using a multi-stage stratified random sampling. First, considering the economic development level, regional location, and beef cattle farming scale of cities in Henan Province, four prefecture-level cities were selected as survey sites: Zhumadian, Kaifeng, Luoyang, and Nanyang (Figure 1). Then, using the same method, three sample counties were selected in each sample city (e.g., Biyang County, Queshan County and Pingyu County in Zhumadian City; Weishi County, Tongxu County and Qi County in Kaifeng City; Yichuan County, Luoning County and Yiyang County in Luoyang City; Fangcheng County, Tanghe County and Dengzhou County in Nanyang City), and 25 beef cattle farms were randomly selected in each sampled county, resulting in a research sample of 300 beef cattle farms. The formal survey was conducted in the form of one-to-one interviews with the beef cattle farmers. The response rate is 96.3%, with 289 questionnaires collected. A total of 276 valid questionnaires were finally obtained after excluding invalid responses (e.g., due to self-contradiction or missing variables), with an effective rate of 95.5%.

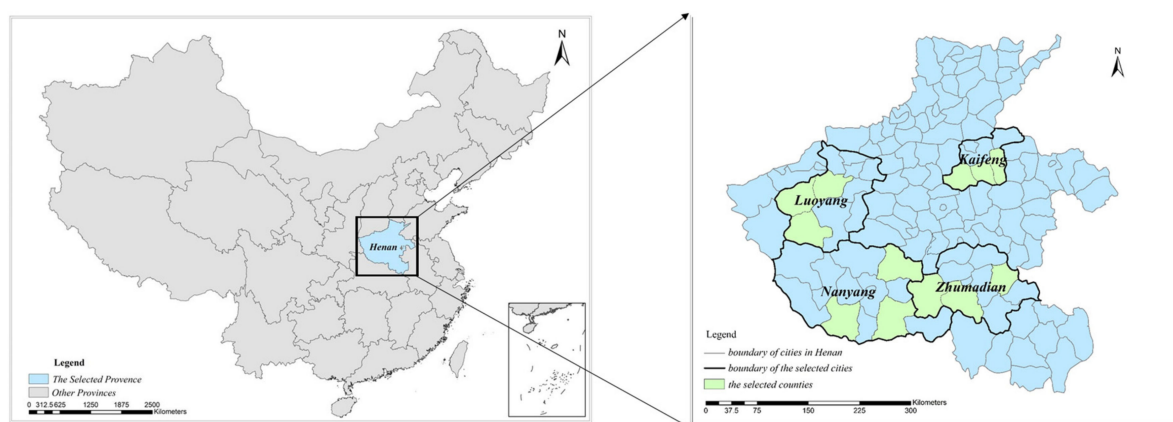


Figure 1. Maps of the study site.

The majority of agricultural training in China is provided free by government agencies as public welfare. The three types of training—policy publicity, technical guidance, and field trips—are typically cross conducted and even mixed into hybrid training. For example, policy publicity is often embedded in technical guidance and field trips. The goal of such agricultural training is to promote sustainable farming practices, despite different types of training. Because our survey data does not distinguish between alternative types of training, we focus on the aggregate impact of training on farmers' installation of biogas digesters in this study. A fruitful line of future research is to collect field data and explore how different types of training affect farmers' behavior.

2.2.2. Variables and Descriptive Statistics

The dependent variable used in the main analysis is whether a beef cattle farmer has installed biogas digesters to manage livestock manure. If the farmer has installed biogas digesters, the explained variable is assigned 1; otherwise, it is assigned 0. An alternative dependent variable—the willingness of beef cattle farmers to install biogas digesters—is later used in a robustness test. If a farmer is willing to install biogas digesters, the alternative dependent variable is assigned 1, otherwise it is assigned 0. Two alternative core independent variables are examined. One is whether a beef cattle farmer has participated in training related to sustainable farming practices. If a farmer has participated in training, the core explanatory variable is assigned 1; otherwise, it is assigned 0. The other is the amount of training that a farmer has received in sustainable farming practices.

With reference to existing relevant studies [54–57], 14 control variables that may affect the installation of biogas digesters by beef cattle farmers are introduced. These control variables fall into two groups. The first group of variables focuses on individual characteristics, which include age, education level, health status, farming experience,

leadership experience, family size, and risk perception of the operator of a farm (i.e., the farmer). The second group of variables focuses on farm characteristics, which include farm size, planting area, land leasing, farm location, farming income, peer effect, and farming award. Table 1 describes all the variables and reports their descriptive statistics.

Table 1. Variable definitions and summary statistics.

Variable Name	Variable Definition	Mean	SD
<i>Dependent variable</i>			
Willingness	If willing to install biogas digesters (1 = yes, 0 = no)	0.486	0.501
Biogas	If installed biogas digesters (1 = yes, 0 = no)	0.065	0.247
<i>Independent variable of interest</i>			
Training	If participated in training related to sustainable farming practices (1 = yes, 0 = no)	0.580	0.495
Training intensity	Number of trainings that farmers received related to sustainable farming practices	1.25	1.449
<i>Control variables</i>			
<i>Individual characteristics</i>			
Age	Age of a farmer (years)	47.246	10.229
Education level	Primary school or lower = 1, junior = 2, high school or technical secondary school = 3, beyond high school = 4	2.482	1.036
Health status	From very poor to very good, assigned from 1 to 5	4.228	0.904
Farming experience	Years of farming (years)	7.011	5.917
Leadership experience	Being a village cadre or not (1 = yes, 0 = no)	0.094	0.293
Family size	Number of family numbers	5.341	2.061
Risk perception	Agricultural pollution may cause conflicts with surrounding residents (from very unlikely to very likely, assigned from 1 to 5)	2.225	1.227
<i>Farm characteristics</i>			
Farm size	Numbers of cattle in stock at the end of 2017 (heads)	97.844	189.191
Planting area	Crop acreage (acres)	63.063	203.045
Land leasing	If leased land (1 = yes, 0 = no)	0.533	0.500
Farm location	Distance from the farm to town/urban center (km)	5.518	3.632
Farming income	Proportion of household income from cattle farming (%)	68.727	25.234
Peer effect	If affected other farmers' behavior or not (1 = yes, 0 = no)	0.533	0.500
Farming award	If received sustainable farming award (1 = yes, 0 = no)	0.725	0.448

In the data sample, 160 farmers participated in agricultural training, accounting for about 57.97% of the total of the surveyed farmers. This suggests that beef cattle farmers have high enthusiasm to participate in training related to sustainable farming practices. For training intensity (i.e., the number of times a farmer participates in the training), most farmers tend to participate one or two times. Additionally, the number of farmers who participated in the training one or two times is similar, accounting for 21.38% and 20.29% of the total sample, respectively. Farmers in this sample participated a maximum of six times in the given training. A total of six farmers participated in the training six times, and another six farmers participated in the training five times, both of which account for 2.17% of the total sample (Figure 2).

In terms of biogas digester installation, as shown in Table 2, 134 farmers are willing to install biogas digesters, accounting for about 48.55% of the total sample, while 51.45% of farmers are unwilling to install biogas digesters. Generally speaking, beef cattle farmers are reluctant to install biogas digesters. It is also reflected in the actual actions of farmers. Only 18 farmers have installed a biogas digester (93.48% of farmers have not installed one), and the actual installation ratio of biogas digesters by farmers is much lower than the willingness to install. This is consistent with Kiratikarnkul's [9] research results, which show that farmers are reluctant to adopt biogas technology. One possible reason for this is that the economic feasibility of anaerobic digestion is not good [5,10]. In addition, there are other alternative manure management systems of advantages that can be chosen, such as compost-based systems, product-based systems, and substrate-based systems [57].

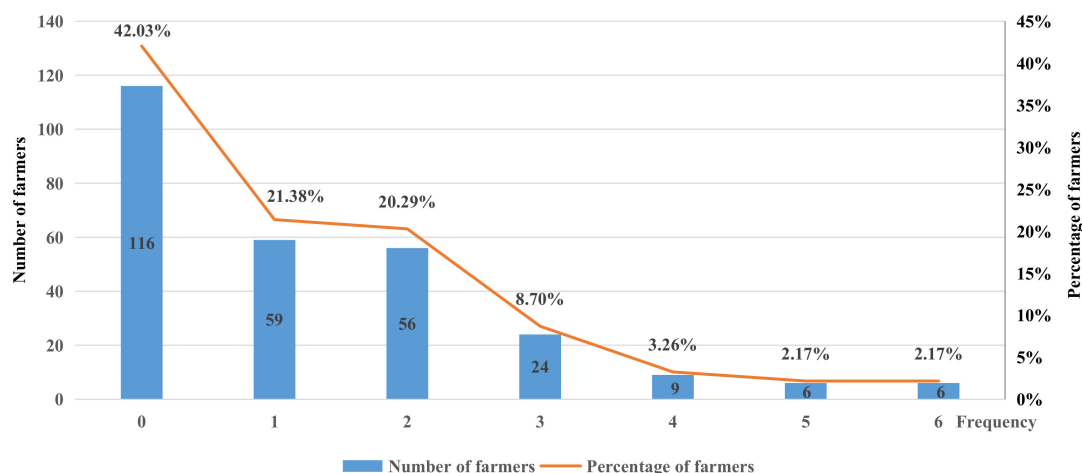


Figure 2. Distribution of farmers participating in training.

Table 2. Farmers' willingness-to-install and installation of biogas digesters.

	Yes		No	
	Number of Farmers	Percentage of Farmers	Number of Farmers	Percentage of Farmers
Willingness to install	134	48.55%	142	51.45%
Have installed	18	6.52%	258	93.48%

In terms of the investment intensity in biogas digesters, the average investment of 18 farmers in the installation of biogas digesters is about 104,000 RMB, and the maximum investment is about 300,000 RMB. The size of biogas digesters is mostly small, similar to household biogas digesters (with a treatment volume less than 600 m³). The inputs to digesters are mainly beef cattle manure produced on farm, mixed with some crop straw. Some farmers also supplement it with a small amount of manure from other livestock stocked on the farm. Because of the average small farm size, the low gas production rate of beef cattle manure, and the limited availability of supplemental inputs, the amount of biogas produced from beef cattle manure by biogas digesters is insufficient to support commercial purposes such as grid connected power generation. Biogas produced is mainly used for combustion and heating onsite. After solid-liquid separation, the biogas slurry and biogas residue are directly applied to cropland or stored for later land application. Only a few farmers have the capacity to dry up the biogas residue for sales or as cow mattress material. Therefore, from the perspective of economic returns, the incentive for beef cattle farmers, especially small-scale farmers, to install biogas digesters is low, which weakens their willingness in installing biogas digesters. Moreover, some farmers cannot afford to install and maintain biogas digesters [58]. Nevertheless, if necessary technical and financial support is extended to help farmers produce and use biogas, biogas production from anaerobic digestion can become an attractive option [9]. This is also one of the objectives of offering agricultural training, which is to improve the possibility for farmers to obtain various supports.

3. Results and Discussion

3.1. Impact of Training on Biogas Digesters Installation

We run two alternative regressions of the probit model in the Stata15.0 software. The first regression (regression 1) includes only the core explanatory variable (i.e., training) in the estimation, while the second regression (regression 2) includes the control variables to partial out potential covariations for better estimation of the marginal effect. The estimation results are shown in Table 3. In regression (1), the coefficient of the training variable is

positive and statistically significant at the 5% confidence level. After introducing the control variables in regression (2), the coefficient of the training variable remains positive and statistically significant at the 5% confidence level, but with a lower magnitude compared to that in regression (1). The results indicate that the training experience increases the probability of biogas digester installation by 5.5%, as shown by the marginal effect in regression (2). Compared to the results in regression (1), the marginal effect of training decreases from 7.7% but remains significant in promoting the installation of biogas digesters in beef cattle farmers. This is in favor of the hypothesis that training has a significant effect in promoting livestock farmers to install biogas digesters to manage manure. The results are consistent with previous findings that technical and policy support are two key factors for the installation of biogas digesters [9,26]. Public training programs can improve the profit expectation and feasibility of installing biogas digesters, and thus can be an effective method to promote the installation of biogas digesters.

Table 3. Estimated impact of training on biogas digester installation.

Variables	Regression (1)		Regression (2)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
<i>Independent variable of interest</i>				
Training	0.627 ** (0.282)	0.077 ** (0.036)	0.526 ** (0.273)	0.055 ** (0.027)
<i>Control variables</i>				
<i>Individual characteristics</i>				
Age			0.012 (0.013)	0.001 (0.001)
Education level (Primary school or lower is the reference group)				
junior			0.505 (0.485)	0.025 (0.026)
high school or technical secondary school			1.097 *** (0.410)	0.091 *** (0.030)
beyond high school			1.062 ** (0.477)	0.085 ** (0.043)
Health status			−0.185 (0.145)	−0.019 (0.015)
Farming experience			0.041 ** (0.020)	0.004 ** (0.002)
Leadership experience			−0.728 (0.463)	−0.076 (0.049)
Family size			0.004 (0.057)	0.0004 (0.006)
Risk perception			0.035 (0.085)	0.004 (0.009)
<i>Farm characteristics</i>				
Farm size (Take logarithm)			−0.099 (0.134)	−0.010 (0.014)
Planting area (Take logarithm)			0.144 (0.107)	0.015 (0.010)
Land leasing			−0.249 (0.338)	−0.026 (0.034)
Farm location (Take logarithm)			0.252 ** (0.127)	0.026 * (0.014)
Farming income			0.080 (0.544)	0.008 (0.057)
Peer effect			0.329 (0.288)	0.034 (0.029)
Farming award			−0.452 (0.281)	0.047 * (0.029)
Constant	−1.945 *** (0.246)		−3.074 *** (1.190)	
Sample size	276		276	
Log pseudolikelihood	−63.706		−53.169	
Pseudo R ²	0.043		0.201	

Note: The values in parentheses are robust standard errors; ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

For the control variables, the education level can significantly affect cattle farmers' decisions on whether to install biogas digesters. On the impact of the education level, compared to the reference group of primary school or lower, farmers who finished high school or beyond are more likely to install biogas digesters by 9.1% and 8.5% for these two groups, respectively. It indicates that a higher education level positively motivates farmers to install biogas digesters. The results may be related to the characteristics of a biogas digester. The installation of biogas digesters is a highly professional and technical process, with specific knowledge required for the operation and maintenance. The farmers

with higher education levels have a better learning capacity and ability to adopting new technology [36]. Therefore, they are more capable of installing and operating a biogas digester. This is consistent with existing studies that suggest that farmers with higher education levels are more likely to adopt new technology or practices than the less-educated farmers [59]. Moreover, among all factors affecting the installation of biogas digesters, the marginal effect of the education level is the largest. The location of a farm also plays a significant role in promoting biogas digesters. The farther away a farm is from a town or urban center, the more likely it will install biogas digesters by an average of 2.6%. The distance from farm to town/urban centers means the convenience of accessing the market. For beef cattle farms located farther from urban centers, it is more challenging to manage manure with market-oriented approaches such as producing organic fertilizer from biogas digestion, whereas returning manure to cropland is largely limited by the land scale [32,34]. Therefore, these farmers are less likely to install biogas digesters. The farming experience variable is positive and statistically significant at the 5% level, indicating that the farming experience can significantly promote biogas digester installation, though with a relatively small magnitude of 0.4% on average. Farmers with longer experience in cattle farming can accumulate more understanding and technological preparations in using a biogas digester, which leads to a higher probability of installation.

3.2. Impact of Training Intensity on Biogas Digesters Installation

We further explore the impact of training intensity on biogas digester installation by replacing the training dummy variable with the amount of training that farmers receive in sustainable farming practices. Similarly, we run two alternative regressions, one with only the core explanatory variable (regression 3) and the other with the control variables included (regression 4). The estimation results are shown in Table 4. Without the control variables, the training variable is positive and statistically significant at the 1% confidence level. When controlling for the other factors, the training variable remains positive and statistically significant, and the marginal effect on probability decreases slightly from 2.4% to 2.0% between regressions (3) and (4). The results suggest that more intense training leads to a higher probability of installing biogas digesters, which is in favor of our research hypothesis and complements the results from Table 3.

3.3. Robustness Test

As a robustness test, the dependent variable is replaced by the willingness of the beef cattle farmers to install biogas digesters. The key estimated results of the probit model are shown in Table 5 with regression (5) being the single variable model and regression (6) including control variables. The training dummy variable is significant at the statistical level of 1% in both regressions, indicating that training can significantly promote the willingness of cattle farmers to install biogas digesters. The findings are consistent with the main results in Sections 3.1 and 3.2. In terms of marginal effects, the coefficient of the training variable in Table 5 has a magnitude of 18.7% in regression (6), higher than that in Tables 3 and 4. The results indicate that training activity spurs more willingness than action to install biogas digesters (5.5%) among cattle farmers. This is not counter intuitive because the willingness to install biogas digesters does not necessarily transform into actual installation due to economic or other constraints. As shown in the sample descriptive statistical analysis in Table 2, the number of farmers willing to install biogas digesters (134) is much larger than the number of farmers that actually installed biogas digesters (18), and this has been widely confirmed in various existing studies [43,60,61].

Table 4. Estimated impact of training intensity on biogas digester installation.

Variables	Regression (3)		Regression (4)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
<i>Independent variable of interest</i>				
Training	0.199 *** (0.063)	0.024 *** (0.009)	0.197 *** (0.070)	0.020 *** (0.007)
<i>Control variables</i>				
Individual characteristic				
Age			0.010 (0.013)	0.001 (0.001)
Education level (Primary school or lower is the reference group)				
junior			0.609 (0.456)	0.030 (0.025)
high school or technical secondary school			1.126 *** (0.404)	0.087 *** (0.028)
beyond high school			1.165 ** (0.472)	0.093 ** (0.045)
Health status			−0.168 (0.142)	−0.017 (0.014)
Farming experience			0.045 ** (0.020)	0.005 ** (0.002)
Leadership experience			−0.834 * (0.496)	−0.085 * (0.051)
Family size			0.001 (0.059)	0.0001 (0.006)
Risk perception			0.027 (0.088)	0.003 (0.009)
Farm characteristics				
Farm size (Take logarithm)			−0.103 (0.130)	−0.011 (0.013)
Planting area (Take logarithm)			0.141 (0.106)	0.014 (0.010)
Land leasing			−0.329 (0.340)	−0.034 (0.033)
Farm location (Take logarithm)			0.191 * (0.114)	0.020 (0.012)
Farming income			−0.057 (0.551)	−0.006 (0.056)
Peer effect			0.328 (0.313)	0.034 (0.031)
Farming award			−0.421 (0.272)	−0.043 (0.027)
Constant	−1.829 *** (0.157)		−2.788 ** (1.227)	
Sample size	276		276	
Log pseudolikelihood	−63.044		−52.414	
Pseudo R ²	0.053		0.212	

Note: The values in parentheses are robust standard errors; ***, ** and * represent 1%, 5% and 10% statistical significance levels, respectively.

Table 5. Estimated impact of training on willingness to install biogas digesters.

Variables	Regression (5)		Regression (6)	
	Coefficient	Marginal Effect	Coefficient	Marginal Effect
<i>Independent variable of interest</i>				
Training	0.542 *** (0.156)	0.209 *** (0.057)	0.531 *** (0.176)	0.187 *** (0.059)
<i>Control variables</i>				
Constant	−0.353 *** (0.119)		0.160 (0.740)	
Sample size	276		276	
Log pseudolikelihood	−185.030		−170.750	
Pseudo R ²	0.032		0.107	

Note: The values in parentheses are robust standard errors; *** represent 1% statistical significance levels.

To avoid the selection bias caused by sample self-selection, this study further uses a propensity score matching (PSM) method to test the impact of training on farmers' installation of biogas digesters. Based on the balance test and the common support test of the matching variable, four matching methods are adopted: k-nearest neighbor matching (one-to-one matching), radius matching, nearest-neighbor matching with caliper, and kernel matching. The average treatment effect results of the outcome variable are shown in Table 6. The results from the four matching methods are relatively consistent, and all show that the training has a significant role in promoting farmers to install biogas digesters. Based on the mean value of the average treatment effect on the treated (ATT), participating in training

increases the probability of installing biogas digesters by 8.0%, which again demonstrates the robustness of the results in this study.

Table 6. Estimation results of propensity score matching (PSM) methods.

	Matching Methods				ATT Mean
	k-Nearest Neighbor Matching	Radius Matching	Nearest-Neighbor Matching within Caliper	Kernel Matching	
Installing biogas digesters	0.088 *** (0.031)	0.079 ** (0.035)	0.075 ** (0.033)	0.079 ** (0.032)	0.080

Note: The values in parentheses are robust standard errors; ***, ** represent 1%, 5% statistical significance levels, respectively. The ATT mean is the mean value of the average treatment effect on the treated (ATT) obtained from the four matching methods.

4. Conclusions

Anaerobic digestion is one of the leading ways to manage livestock manure for energy production and to move towards carbon neutrality in the agricultural sector. Based on the field survey data of beef cattle farmers in China, this study empirically examines the impact of agricultural training on farmers' installation of biogas digesters to manage livestock manure. The results show that training has a positive impact on both farmers' willingness and the actual installation of biogas digesters, which indicates that training can effectively motivate farmers to install biogas digesters. In terms of the marginal effects, the impact of training on farmers' willingness to install biogas digesters is stronger than that of actual installation. Furthermore, with the increase of training intensity, the probability is higher for farmers to install biogas digesters. For the control variables, the education level and farming experience of a farmer, as well as farm location, are found to also affect the installation of biogas digesters, among which the education level of a farmer is the most significant factor affecting the installation.

Based on the above findings, several policy implications are proposed for promoting anaerobic digestion for livestock manure management. First, agricultural extension and outreach programs should be developed to facilitate the training of livestock farmers and enrich the existing training content, such as policy interpretation and technical guidance. Second, since the education level of a farmer is the most important factor affecting the installation of biogas digesters, vocational education can be strengthened to improve the education level of farmers. In addition, incentives can be provided to encourage personnel with higher levels of education to engage in livestock farming. For example, China encourages highly educated groups, such as college graduates, to start agribusinesses in rural areas by implementing financial subsidies, financial credits, tax incentives, guarantee assistance towards start-up failure, etc. Lastly, because the livestock farming experience also affects the installation of biogas digesters, mentor-mentee programs that pair more-experienced livestock farmers with less-experienced ones can be developed to provide informal training and assistance to new farmers.

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Appendix A

The main contents of the survey questionnaire.

Section A. General information of farmer

1. How old are you? ____ (Years)
2. Are you a village cadre? ()
A. Yes, B. No.
3. What is your educational level? ()
A. Primary school or lower, B. Junior, C. High school or technical secondary school, D. High school or above.
4. How about your health? ()
A. Very poor, B. Poor, C. Fair, D. Good, E. Very good.
5. How long have you been engaged in farming? ____ (Years)
6. How many persons are in your family? ____ (Persons) Among your family members, how many are migrant workers? ____ (Persons)
7. Do you agree with that agricultural pollution may cause conflicts with surrounding residents? ()
A. Very unlikely, B. Unlikely, C. Fair, D. Likely, E. Very likely.

Section B. Basic information of farm

8. How many heads of beef cattle did your farm have in stock at the end of 2017? ____ (Heads)
9. What is the total acreage of your farm? ____ (Acres)
10. What is the crop acreage of your farm? ____ (Acres)
11. Have you ever leased in land? ()
A. Yes, B. No.
12. Have you ever leased out land? ()
A. Yes, B. No.
13. How far is it from the farm to town/urban center? ____ (km)
14. What is the proportion of your household income from cattle farming in 2017? ____ (%)
15. Have you ever affected other farmers' behavior? ()
A. Yes, B. No.
16. Have you ever received sustainable farming award? ()
A. Yes, B. No.

Section C. Environmentally friendly behavior

17. Have you ever participated in training related to sustainable farming practices? ()
A. Yes, B. No.
18. How many times have you participated in training related to sustainable farming practices? ____ (Times)
19. Are you willing to install biogas digesters? ()
A. Yes, B. No.
20. Have you installed biogas digesters? ()
A. Yes, B. No.

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