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Impact of nudge strategies on carbon emission reduction behavioral decisions of dairy farmers

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With the intensification of global climate change, reducing carbon emissions in the livestock industry has become essential for promoting low-carbon agricultural transformation. This study investigates how nudge strategies influence carbon reduction decision-making among dairy farmers in Shandong Province, China. Two types of nudge strategies—default options and social norms—were examined. Data were collected using a mixed-methods approach, including questionnaires, field interviews, and official government statistics. A total of 311 questionnaires were distributed, with 198 valid responses analyzed. The sampling strategy combined random and stratified sampling to ensure representativeness. Quantitative data were analyzed using stepwise regression models and instrumental variable (IV) methods to evaluate the effects of nudge strategies on carbon reduction behavior. Results show that both default options (e.g., implicit recommendation, limited cognition, loss aversion, and optimal consultation) and social norms (e.g., reference effect, cognitive preference, risk aversion, and peer pressure) significantly and positively affect farmers' carbon reduction behaviors. These strategies operate through complete mediation mechanisms. Additionally, younger farmers and those operating smaller-scale farms were found to be more susceptible to the influence of nudge strategies. Findings highlight the effectiveness of nudge strategies in promoting low-carbon behaviors among dairy farmers. This suggests that incorporating such behavioral interventions into agricultural policies could enhance the adoption of carbon reduction measures. Targeted implementation, enhanced policy incentives, and technical support are recommended to advance low-carbon and sustainable development in the dairy farming sector.

KEYWORDS

carbon emission reduction, dairy farmers, nudge strategies, default options, social norms

1 Introduction

Global climate change, driven by greenhouse gas emissions, remains a critical challenge. Under the Paris Agreement, nations aim to limit global temperature rise to below 2°C, with efforts to achieve a 1.5°C target. Agriculture, particularly livestock farming, is a major contributor to greenhouse gas emissions, primarily through methane (CH_4) from enteric fermentation and nitrous oxide (N_2O) from manure management. Dairy farming, as a key component of this sector, has become a focal point for emission reduction strategies. In China, livestock farming significantly contributes to agricultural carbon emissions, with dairy farming playing a pivotal role. The Chinese government has committed to peak carbon emissions by 2030 and achieve carbon neutrality by 2060, implementing policies such as financial incentives,

technological advancements, and carbon trading mechanisms to promote low-carbon agricultural transformation.

Despite these policy efforts, dairy farmers' adoption of carbon reduction measures varies due to economic constraints, farm size, technological capacity, and awareness of sustainability initiatives. Many farmers face barriers, including limited resources and information asymmetry. Nudge Theory (Thaler and Sunstein, 2008) offers a non-coercive approach to influencing decision-making by structuring choice environments to encourage sustainable behaviors. Strategies such as default options and social norms facilitate the adoption of low-carbon technologies by reducing cognitive and informational burdens. As these interventions are widely endorsed by experts and accepted within society, they present a promising mechanism for enhancing sustainability in the agricultural sector.

Shandong, as a major agricultural province in China, has always maintained a leading position in livestock farming, demonstrating unique regional advantages and development potential. According to the 2024 Statistical Yearbook (National Bureau of Statistics of China, 2024), in 2023, Shandong's meat production reached 9.101 million tons, accounting for 9.3% of the national total, ranking first in the country. The milk production reached 3.181 million tons, representing a year-on-year increase of 4.6%, ranking among the top provinces in the nation. As one of China's major dairy-producing provinces, Shandong has developed a dairy farming industry characterized by large-scale and intensive operations, making it a representative region for studying dairy farming with broader applicability. Large-scale dairy farms and cooperatives dominate the industry, exhibiting a high degree of industrial concentration compared to smallholder farming.

This study investigates the application of nudging strategies in dairy farming in Shandong Province through a large-scale survey experiment, aiming to measure the impact of these strategies on dairy farmers' carbon-reduction decision-making behavior. This research enriches the application of nudging theory in agricultural decarbonization, revealing the crucial role of mediating mechanisms in these strategies. The study quantitatively analyzes how nudging strategies influence individual decision-making through multiple mechanisms, deepening the understanding of this field. Practically, this research provides clear guidance for policy design, emphasizing actionable insights for promoting sustainable agricultural practices. Future studies can extend to broader agricultural sectors, using advanced experimental designs to test the long-term effects of nudging strategies. Furthermore, exploring the synergistic effects of nudging strategies in areas such as technology adoption and market mechanisms will contribute to building a more comprehensive path for low-carbon agricultural transformation.

2 Related literature

2.1 Current status of agricultural greenhouse gas emissions in China

The study of global agricultural greenhouse gas (GHG) emissions has become a critical topic in climate change research. International authoritative institutions, such as the Intergovernmental Panel on Climate Change (IPCC), have indicated that agricultural emissions mainly originate from land-use changes, livestock farming, and fertilizer application (IPCC, 2006, 2007). Among these emissions, methane (CH_4) and nitrous oxide (N_2O) account for approximately 50 and 60% of total anthropogenic emissions, respectively, and their greenhouse effects are significantly higher than that of carbon dioxide (CO_2), highlighting the necessity of adopting a more comprehensive perspective beyond CO_2 in agricultural carbon mitigation research (Smith et al., 2013).

In China, agricultural carbon emissions have become the third-largest emission source after energy and industrial production, with livestock farming contributing a substantial proportion. Studies indicate that between 2010 and 2020, agricultural carbon emissions in China exhibited a steady growth trend, with livestock emissions accounting for 54.3% of total agricultural emissions (Li et al., 2020). Dairy farming, as a key sector of livestock production, faces challenges in emissions estimation and reduction strategies. The expansion of large-scale dairy farming has rendered traditional emission factor-based calculation methods, such as those outlined in the Provincial Greenhouse Gas Inventory Compilation Guidelines (2011), increasingly outdated, necessitating reassessments incorporating the latest data and technological advancements (Chen and Hu, 2016). Additionally, significant regional disparities exist in agricultural carbon emissions across China, and policy regulations and structural optimization of the agricultural sector play a crucial role in determining carbon mitigation effectiveness (Yao et al., 2017).

2.2 Current status of greenhouse gas emissions in the dairy industry

As a vital component of the livestock industry, dairy farming plays a significant role in supplying high-quality dairy products while also contributing substantially to agricultural GHG emissions. Statistics show that China's annual milk production increased from approximately 30.39 million tons in 2010–34.40 million tons in 2020, reflecting a 13.2% growth. In terms of livestock-related GHG emissions, dairy and beef cattle are the largest contributors, accounting for approximately 65% of total emissions, while pig and poultry farming contribute about 9 and 8%, respectively (China Environment Network). With the implementation of the Dairy Industry Revitalization Strategy, China's milk production is projected to reach 40 million tons by 2025, and by 2030, the proportion of large-scale dairy farming is expected to increase significantly, with per-cow milk yield surpassing 10 tons, providing technical and management support for reducing carbon emissions per unit of output (2021–2030 China Dairy Market Outlook Report).

As ruminants, dairy cattle generate significant amounts of methane during digestion, while manure management also leads to emissions of CO_2, CH_4, and N_2O (Qu and Ma, 2022). Research suggests that the annual pollutant emissions from a single dairy cow can have a greater impact on air quality than a small passenger vehicle, and China's livestock sector accounts for more than 50% of global ammonia emissions (Feng and Yang, 2011; Zhang, 2015; Lin et al., 2025). Therefore, controlling carbon emissions from dairy farming is not only critical for the industry's sustainable development but also plays an essential role in regional and global environmental protection.

2.3 Nudge theory

Nudge Theory emphasizes influencing individual behavior by altering decision-making environments and setting default options,

thereby promoting choices that align with social welfare. Unlike coercive measures, nudging operates by optimizing the choice architecture while preserving individual freedom of choice. This approach reduces decision-making costs and increases the adoption rate of desirable behaviors.

Nudge Theory influences individual behavior by optimizing decision-making environments and setting default options, promoting socially beneficial choices while maintaining individual freedom. Rooted in behavioral economics, it acknowledges bounded rationality, willpower, and self-interest, recognizing that cognitive biases—such as loss aversion, overconfidence, and inertia—along with social influences, often lead individuals to suboptimal decisions. Unlike coercive interventions, nudging operates within libertarian paternalism, subtly guiding choices without restricting freedom or altering objective outcomes (Thaler, 2018). A key mechanism is the strategic use of default options—pre-selected choices that individuals passively accept when they do not actively opt out. Policymakers leverage default options to drive significant behavioral shifts in areas such as pension enrollment, organ donation, and pro-environmental actions like renewable energy adoption and waste reduction (Pichert and Katsikopoulos, 2008; Sunstein, 2013). These effects stem from both physical and cognitive mechanisms: individuals adhere to defaults to avoid the effort of opting out (Dinner et al., 2011), while also perceiving them as expert-endorsed or socially accepted, thereby simplifying information processing and decision-making (Thaler and Sunstein, 2008; Sunstein and Reisch, 2014; van Gestel et al., 2020). By reducing decision-making costs and fostering rational choices, nudging enhances both personal and societal welfare, ensuring policy effectiveness with minimal intervention.

In recent years, nudge theory has gained traction in Chinese agriculture, particularly in reducing antibiotic use, promoting sustainability, and protecting arable land. Maertens et al. (2023) showed that micro-subsidies and social norms interventions encouraged farmers to adopt alternative poultry technologies, but uptake was limited, and sanitation measures were not fully implemented, increasing mortality in some cases. Čop and Njavro (2024) identified information, social norms, and social comparison as the most common nudge strategies in agricultural economics. Zhang et al. (2022) proposed six nudge strategies for land protection, combining cognitive and motivational approaches. Wu et al. (2021) advocated embedding nudges in land use planning to balance government intervention and market forces. These studies highlight nudge theory as a promising tool for sustainable agricultural policy in China.

2.4 The impact of default options on individual decision-making

Default options, as a widely adopted nudging strategy, significantly influence individual decision-making across domains such as investment, health, and food preferences by pre-setting choices that most people are likely to follow. Research indicates that the effectiveness of default options depends on their degree of behavioral enforcement and adaptability to the contextual environment, as well as being influenced by individual motivations and situational characteristics (Robinson et al., 2021). The core mechanism of this strategy lies in leveraging cognitive biases such as bounded rationality, loss aversion, and status quo bias, thereby simplifying decision-making processes and enhancing execution efficiency (Donkers et al., 2020). Furthermore, the impact of default options on economic choices and decision-making behavior is closely tied to individuals' internal states, including cognitive load, emotional preferences, and evaluations of the consequences of their choices (Couto et al., 2020).

Studies further suggest that the design of default options can be optimized through the concept of "rational defaults," which involves explaining the rationale and benefits of pre-set options while offering alternatives for minority stakeholders (Desiraju and Dietvorst, 2023). This approach not only enhances the appeal and acceptance of default options but also ensures a balance between serving the majority's interests and addressing the needs of minorities, thereby achieving broader policy effectiveness.

2.4.1 Implied recommendations

Default options are often perceived as implicit endorsements, conveying the designer's approval and trust in a particular choice. Such implicit recommendations lead decision-makers to view the default option as optimal or widely accepted, increasing their likelihood of compliance. By doing so, default options effectively reduce individuals' hesitation and concerns when making choices. For example, default options in travel packages have been shown to increase couples' likelihood of booking upgraded rooms and additional meals, while solo travelers' preferences for lower-tier accommodations and meals remain unchanged (Steffen et al., 2020).

2.4.2 Limited cognition

Individuals often face challenges such as information overload or time constraints during decision-making, making it difficult to comprehensively evaluate all possible options. Default options simplify the decision-making environment, reducing cognitive load and information-processing requirements. This allows individuals to accept pre-set options more easily without incurring the additional cost of complex trade-offs and comparisons.

2.4.3 Loss aversion

Default options capitalize on individuals' heightened sensitivity to potential losses, as people tend to avoid risks or uncertainties associated with changing options. As a result, individuals are more inclined to stick with default choices to mitigate the perceived risks of deviating from them. This psychological mechanism makes default options highly persuasive in influencing behavioral change. For instance, when companies set high-price defaults to encourage consumers to choose more expensive products, such strategies can sometimes backfire (Donkers et al., 2020).

2.4.4 Expert-like guidance

Default options provide decision-makers with a clear path of action, functioning akin to expert consultation. The perceived rationality and specificity of pre-set options reassure individuals that these choices are well-considered and carefully recommended, thereby enhancing their credibility and attractiveness. This guidance feature makes default options particularly valuable in complex decision-making scenarios.

2.5 The impact of social norms on individual decision-making

Social norms refer to unwritten rules and informal understandings that govern social expectations and behaviors (Farrow et al., 2017).

Emphasizing social norms can significantly influence individual decision-making. For instance, dietary choices are often shaped by the behavior of others (Li et al., 2020). Social norms have been validated as effective interventions in various contexts, such as tax compliance (Dai et al., 2023), agricultural product purchasing (Wang and Bu, 2021), and traffic behavior (Cui et al., 2023). Specifically, they are widely observed in promoting energy savings (Zhang et al., 2023), green consumption (Ge and Sheng, 2020), and waste classification (Zhang and Wan, 2021).

Social norms typically manifest as statements like "this is what most people do," thereby influencing individual decisions by presenting behavioral trends (Zhou and Zhang, 2019). The effect of social norms has been well-documented in environmental behaviors such as recycling, energy conservation, and sustainable consumption.

Social norms are powerful mechanisms that significantly influence individual behavior by establishing behavioral expectations and promoting social coordination. They are widely applied in various fields such as consumption habits, health beliefs, environmental actions, and social stability. Although their effectiveness varies depending on culture, environment, and individual characteristics, social norms play a crucial regulatory role in shaping the behavior of individuals and groups. According to relevant research, the influence mechanisms of social norms can be summarized into the following four aspects:

2.5.1 Reference effect

Social norms provide individuals with a behavioral reference or "benchmark," helping them understand appropriate behavior in specific situations. Through this process, social norms can guide behavior, enabling individuals to align their actions with group expectations or mainstream values. For example, in energy - saving or environmental - protection behaviors, individuals often refer to the common behavior patterns of their neighbors or within the community, and then adjust their own behavior to approach the benchmark level (Kleef et al., 2019).

2.5.2 Cognitive preference

Social norms influence individuals' perception and cognition of the consequences of behaviors, thereby changing their behavior choices. Individuals tend to consider norm - compliant behaviors as widely accepted and reasonable, and thus form cognitive preferences by internalizing these norms. For instance, people may view environmental - friendly behaviors not only as a manifestation of social expectations but also as a correct choice. This perception further reinforces behavioral consistency (McDonald and Crandall, 2015).

2.5.3 Risk aversion

Social norms affect behavior decision - making by reducing the social risks that may arise from deviating from the norm. In a group, individuals tend to avoid deviating from mainstream behaviors to minimize the possibility of being excluded or not recognized. This risk - averse mentality prompts people to prioritize behaviors that conform to social norms, especially when facing social supervision or external evaluation (Reynolds, 2018).

2.5.4 Peer pressure

Social norms within a group exert a strong binding force on individual behavior. Peer pressure, by emphasizing "group conformity," makes individuals inclined to imitate or follow the behavior patterns of others to maintain harmonious social relationships and a sense of belonging. For example, in environmental protection or public welfare activities, individuals are often positively influenced by their peers around them and thus participate, demonstrating a higher degree of behavioral consistency (Saracevic and Schlegelmilch, 2021).

3 Research design

3.1 Research subjects and regional selection

The research subjects of this study are dairy farmers in Shandong Province, China. This group was selected based on the following considerations:

Significance of Shandong province: as one of China's major agricultural provinces, Shandong plays a critical role in the nation's livestock industry, particularly in dairy farming. In recent years, the dairy farming sector in Shandong has experienced rapid development, making it a representative case for this study.

Relevance of carbon emissions: carbon emissions from dairy farming processes have become a focal point of environmental concerns. Investigating the carbon reduction decision-making behaviors of dairy farmers holds substantial practical significance.

Diversity in farm scale and operational models: dairy farming in Shandong Province exhibits high levels of industrialization and diverse operational models. These characteristics provide a wide range of samples and data to support the study.

3.2 Characteristics of the research subjects

3.2.1 Geographic distribution and scale

Shandong Province, located in eastern China, features favorable climatic conditions and abundant land resources, creating an ideal environment for dairy farming. Dairy farmers are primarily concentrated in the plains of northwest, central, and southeast Shandong, areas known for their advanced agricultural and livestock industries. These regions are characterized by large-scale operations and high dairy cattle populations.

The research subjects are categorized into two groups:

Small-scale family farms: typically housing dozens of dairy cattle, these farms employ traditional farming practices.

Large-scale intensive farms: housing hundreds or even thousands of dairy cattle, these farms operate with modernized management and advanced technology.

Significant differences in carbon emission behaviors exist between these two groups, making them focal points of this study.

3.2.2 Operational models and technological levels

The operational models of dairy farmers in Shandong include self-breeding and raising, cooperative farming, and the company + farmer model.

Small-scale family farms: rely on traditional practices and have higher carbon emission intensity.

Cooperative and company + farmer models: leverage resource integration and scaled production to achieve partial carbon reduction.

Large-scale farms commonly adopt modern technologies such as precision feeding, waste management systems, and energy-efficient equipment, significantly reducing carbon emissions. In contrast, small-scale farms face financial and technological constraints, limiting their ability to implement effective carbon reduction measures.

3.2.3 Economic conditions and social awareness

Economic capacity plays a crucial role in influencing farmers' carbon reduction behaviors. Large-scale farms, with greater financial resources, can invest in environmental facilities and technological upgrades, whereas small-scale farms often lack sufficient resources for environmental initiatives.

Social awareness levels also vary significantly. Some farmers have limited knowledge of national carbon reduction policies and exhibit low environmental awareness. Conversely, farmers who have received training or participated in educational programs display stronger intentions to engage in carbon reduction activities.

3.2.4 Policy environment and market influence

Policy and market dynamics are critical factors influencing farmers' behaviors. In recent years, Shandong Province has implemented policies such as technology subsidies and environmental rewards to encourage the development of low-carbon agriculture, effectively promoting carbon reduction among farmers.

Additionally, rising market demand for green and low-carbon agricultural products has pressured some large-scale farms to adopt branding and green certification strategies to meet new market requirements. However, small-scale farms experience relatively limited market-driven incentives.

3.3 Data collection

This study employs a combination of three data collection methods: questionnaire surveys, in-depth interviews, and the use of government statistical data. This approach ensures the acquisition of comprehensive and reliable data.

Questionnaire surveys: the primary data collection method is a structured questionnaire survey. The questionnaire is designed to cover multiple aspects, including carbon reduction behaviors, policy awareness, technology adoption, and operational models. It was developed based on pre-surveys and expert consultations to ensure scientific rigor and validity.

Sampling: a combination of random sampling and stratified sampling is employed to select dairy farmers from different regions, farm scales, and operational models across Shandong Province.

Administration: the surveys employ a combination of random sampling and stratified sampling to select dairy farmers from various cities (e.g., Weifang, Jinan, Yantai, etc.) and different scales of dairy farms in Shandong Province. First, the sample is stratified based on cities and farm sizes, with random sampling conducted within each stratum. Then, the sampling proportion for each stratum is determined based on their relative share, ensuring that the sample is representative. Finally, the sample size for each stratum is determined according to the number of dairy farmers in each stratum, and questionnaires are distributed to selected dairy farmers for data collection.

In-depth interviews: to gain deeper insights into the decision-making processes behind carbon emission behaviors, a series of in-depth interviews are conducted.

Participants: interviewees include typical farmers identified through the survey, local government officials, and agricultural technology experts.

Methodology: semi-structured interviews are used to collect qualitative data on key topics such as farmers' understanding of policies, their responses to carbon reduction initiatives, motivations for technology adoption, and perceived barriers. This qualitative data complements and enriches the survey findings.

Government statistical data and industry reports: existing government statistics and industry reports are utilized to supplement the primary data collected. These sources provide additional context and fill in any gaps in the data.

Ethical considerations: ethical guidelines are strictly adhered to during the data collection process. Participant confidentiality and transparency in data collection are prioritized. All data collected is used solely for academic research, and appropriate measures are taken during data processing and analysis to protect the privacy of respondents.

The following are the results after data collection, presented in the form of pie charts (Figures 1, 2).

3.4 Research hypotheses

From both practical and scientific perspectives, this study adopts a field experiment approach to collect the necessary data. In practice, nudge strategies have already demonstrated significant success in developed countries such as those in Europe and North America. However, in China, there has been no systematic government-level implementation or large-scale promotion of these strategies. To investigate whether the potential carbon reduction decision-making mechanisms of dairy farmers align with the effectiveness of nudge strategies, existing observational data from the current environment is insufficient, necessitating experimental data collection.

Based on the analysis of the mechanisms through which nudge strategies influence dairy farmers and how external conditions moderate these effects, the following hypotheses are proposed:

> *H1*: Default options and social norms, as nudge strategies, can effectively motivate dairy farmers to adopt carbon reduction measures.
>
> *H2*: Default options promote carbon reduction among dairy farmers through implicit recommendations, bounded rationality, loss aversion, and optimal consultation, while social norms exert their influence via the reference effect, cognitive preferences, risk aversion, and peer pressure.

4 Research methods and variable selection

4.1 Variable selection

The study begins with descriptive statistical analysis to outline the basic characteristics of the sample, including the education level,

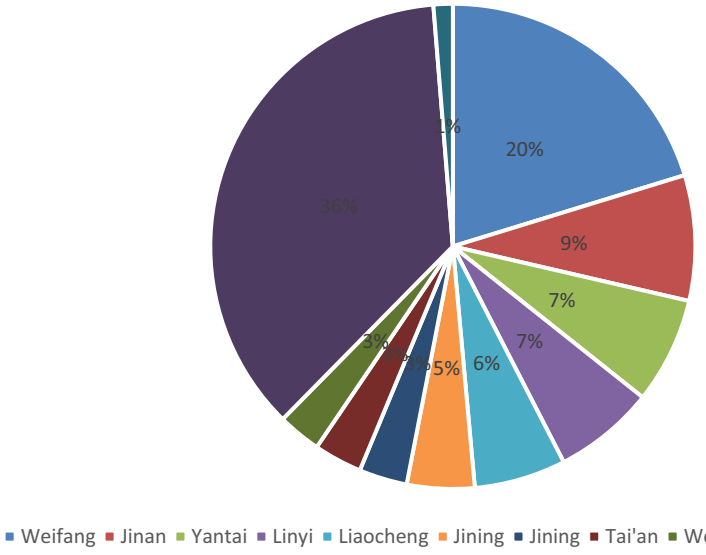

FIGURE 1
Proportion of survey responses collected from cities in Shandong province at the prefecture level.

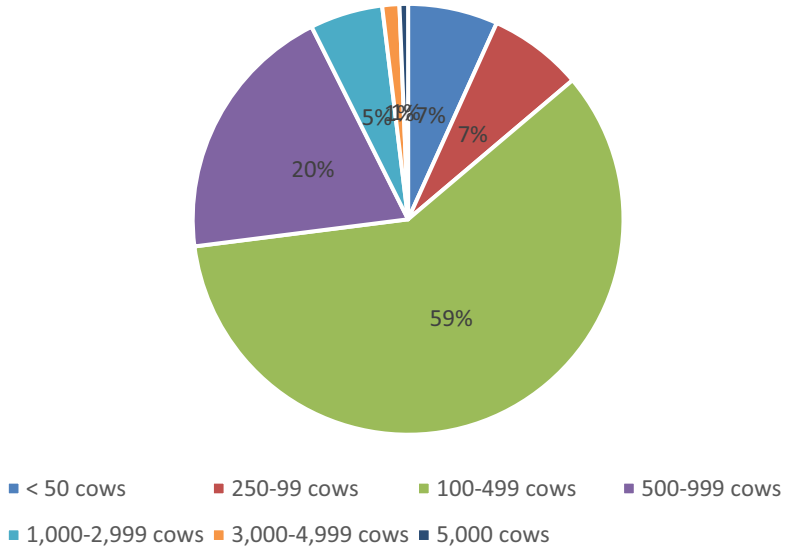

FIGURE 2
Proportion of dairy farm sizes in Shandong province.

operational scale, economic sources, and policy awareness of dairy farmers. This descriptive analysis provides an overview of the sample distribution and establishes a foundational understanding for subsequent regression analyses.

4.1.1 Dependent variable

The dependent variable is carbon reduction behavior of dairy farmers (Y), achieved through the use of nudge strategies. The carbon reduction behavior is measured as an ordered categorical variable, with seven levels ranging from "no carbon reduction" (Carlsson et al., 2019) to "comprehensive carbon reduction" (Dai et al., 2023). Do dairy farmers reduce carbon emissions through the use of nudging strategies (carbon emission reduction initial stage = 1; carbon emission reduction observation stage = 2; carbon emission reduction basic improvement stage = 3; carbon emission reduction moderate improvement = 4; carbon emission reduction efficient stage = 5; deep carbon emission reduction = 6; complete carbon emission reduction = 7).

4.1.2 Explanatory variables

Default options: whether the dairy farmers use default options as a nudge strategy to reduce carbon emissions.

Social norms: whether the dairy farmers adopt social norms as a nudge strategy to reduce carbon emissions.

4.1.3 Control variables

The control variables include the following socioeconomic and operational characteristics of dairy farmers:

Age of the household head.

Education level of the household head: The educational attainment of dairy farmers is categorized as follows: primary school or below (Carlsson et al., 2019), middle school (Carlsson et al., 2021), high school (Chen and Hu, 2016), and college or above (Čop and Njavro, 2024).

Presence of other sources of income "Whether there are other sources of income: Yes (0) No (Carlsson et al., 2019)."

Size of the dairy farm "The scale of dairy farms is categorized as follows: small-scale farms with fewer than 50 cows (Carlsson et al., 2019), medium-small farms with 50–99 cows (Carlsson et al., 2021), medium-scale farms with 100–499 cows (Chen and Hu, 2016), medium-large farms with 500–999 cows (Čop and Njavro, 2024), large-scale farms with 1,000–2,999 cows (Couto et al., 2020), very large-scale farms with 3,000–4,999 cows (Cui et al., 2023), and mega-scale farms with more than 5,000 cows (Dai et al., 2023)."

Number of contracts signed with enterprises (The number of enterprise contracts signed by dairy farmers).

4.1.4 Mediating variables

The mediating variables represent specific mechanisms within the nudge strategies that influence carbon reduction behavior:

Whether the farmer reduces carbon emissions through *implicit recommendation.*

Whether the farmer reduces carbon emissions through *limited cognition.*

Whether the farmer reduces carbon emissions through *loss aversion.*

Whether the farmer reduces carbon emissions through *optimal consultation.*

Whether the farmer reduces carbon emissions through the *reference effect.*

Whether the farmer reduces carbon emissions through *cognitive preference.*

Whether the farmer reduces carbon emissions through *risk aversion.*

Whether the farmer reduces carbon emissions through *peer pressure.*

4.1.5 Instrumental variable (IV)

Policy subsidies received by the dairy farmer (The number of policy subsidy programs received within 3 years).

4.2 Model construction

Given that the dependent variable, "the extent to which dairy farmers adopt nudging strategies for carbon emission reduction," is an ordered categorical variable, this study employs an ordered model to quantitatively analyze the influencing factors on participation willingness.

Considering that existing research categorizes nudging strategies into two commonly used tools—default options and social norms—this study focuses on examining the impact of these two strategies on dairy farmers' carbon reduction decision-making behavior. The econometric model is constructed as follows:

$$CB_i^m = \alpha_{10}^m + \alpha_{11}^m DO_i + \alpha_{12}^m SN_i + \sum \lambda_{1k}^m X_{ki} + \varphi_{1i}^m$$

Where:

CB: Indicates whether the household head adopts a certain carbon reduction technology under the influence of nudging strategy interventions.

i: Represents the index of the sampled farmer.

m: Denotes the index of specific carbon reduction technologies.

DO and SN: Represent the effects of default options and social norms as two major nudging strategies applied to the household head.

X: Denotes control variables, with k representing the index of the control variables.

α: Parameters to be estimated.

ϕ: Random disturbance term.

This study aims to explore the mechanisms through which default options and social norms influence dairy farmers' carbon reduction decision-making behavior. Based on existing theories and empirical studies, the potential influencing factors of default options on farmers' carbon neutrality decision-making are categorized into four dimensions: implied recommendations, loss aversion, limited cognition, and expert-like guidance. Meanwhile, the potential influencing factors of social norms are divided into four aspects: reference effects, cognitive preferences, risk aversion, and peer pressure.

An extended model is constructed as follows:

$$\begin{aligned} CB_i^m &= \alpha_1^m + \alpha_2^m DO_i + \alpha_3^m SN_i + \sum \lambda_{1k}^m X_{ki} + \varphi_{1i}^m \\ IC_{ni}^m &= \alpha_{4n}^m + \alpha_{5n}^m DO_i + \alpha_{6n}^m SN_i + \sum \lambda_{2kn}^m X_{ki} + \varphi_{2ni}^m \\ CB_i^m &= \alpha_7^m + \sum IC_{ni}^m \left(\alpha_{8n}^m + \alpha_{9n}^m DO_i + \alpha_{10n}^m SN_i \right) \\ &\quad + \alpha_{11}^m DO_i + \alpha_{12}^m SN_i + \sum \lambda_{3k}^m X_{ki} + \varphi_{3i}^m \end{aligned}$$

Where:

IC: Indicates whether the household head adopts a certain carbon reduction technology due to the influence of specific factors under nudging strategy interventions.

n: Represents the index of potential influencing factors. Includes the four factors associated with default options (implied recommendations, loss aversion, limited cognition, and expert-like guidance) and the four factors associated with social norms (reference effects, cognitive preferences, risk aversion, and peer pressure).

Grounded in these theoretical dimensions, the study constructs an analytical framework aimed at revealing how nudging strategies influence dairy farmers' carbon reduction decision-making through multi-dimensional mechanisms (Figure 3).

5 Results and discussion

5.1 Reliability and validity testing

The Cronbach's Alpha value for the data is 0.788, which indicates a good level of reliability. According to commonly accepted standards, a Cronbach's Alpha value >0.7 generally suggests that the measurement

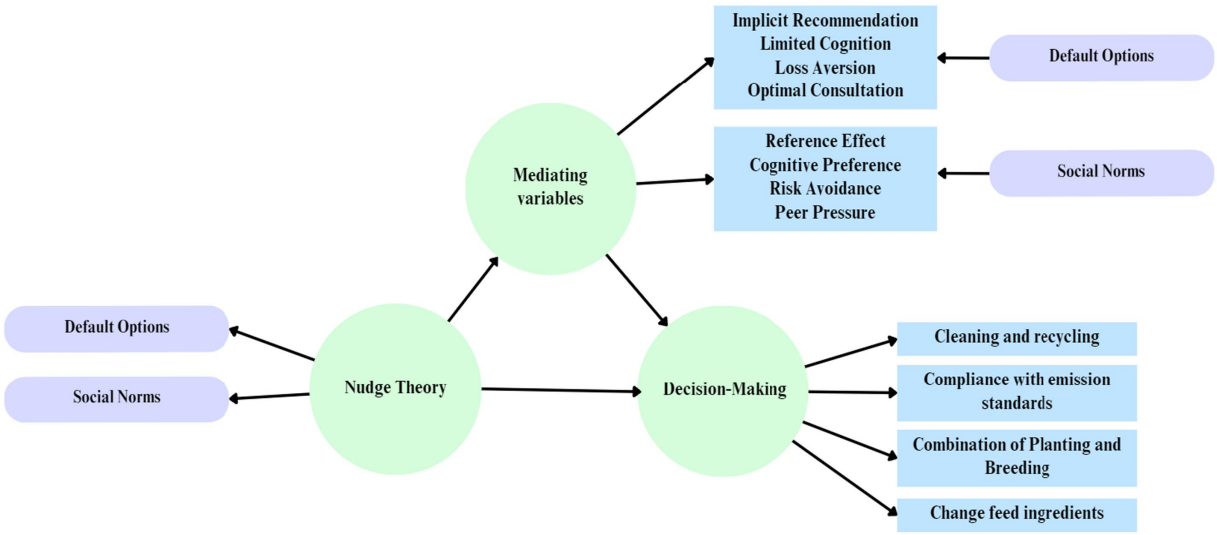

FIGURE 3
Analysis diagram of the mechanisms of nudging strategies on dairy farmers' carbon emission reduction.

instrument has satisfactory internal consistency. The result of 0.788 signifies strong consistency among the items in the survey, with respondents demonstrating a stable response pattern. Thus, the internal consistency of the questionnaire is deemed satisfactory.

The Kaiser-Meyer-Olkin (KMO) coefficient is 0.632, which exceeds the minimum standard of 0.6, indicating that the data is suitable for factor analysis. The KMO value ranges from 0 to 1, with values closer to 1 suggesting strong correlations among the variables. Although the value of 0.632 indicates that the correlation is not very strong, it is sufficient to proceed with factor analysis. Furthermore, the significance level of the KMO test is <0.05, which allows us to reject the null hypothesis (that the variables are uncorrelated), thereby verifying that the data's correlation is adequate to support factor analysis.

5.2 Regression analysis

To analyze the influence of various external conditions on farmers' decisions to adopt nudging strategies for carbon emission reduction, this study employed stepwise regression analysis. The model assumes that the random variables follow a logistic probability distribution, specifically focusing on whether farmers choose nudging strategies for carbon emission reduction. Regression analysis quantifies the impact of different external conditions on farmers' decision-making and explores the effects of four potential factors under default options (implied recommendations, limited cognition, loss aversion, and expert-like guidance) and four potential factors under social norms (reference effects, cognitive preferences, risk aversion, and peer pressure) on carbon reduction behavior.

According to the regression results in Table 1, both default options and social norms, as components of nudging strategies, have a significant positive effect on dairy farmers' carbon emission reduction behavior at the 1% significance level. This finding demonstrates that default options and social norms effectively encourage dairy farmers to adopt carbon reduction measures, thereby validating Hypothesis 1.

5.2.1 Results analysis

The results from Tables 2, 3 reveal that the four mediating factors under default options (implied recommendations, limited cognition, loss aversion, and expert-like guidance) and the four mediating factors under social norms (reference effects, cognitive preferences, risk aversion, and peer pressure) all have a significant positive impact on carbon reduction behavior at the 1% significance level.

Further analysis, integrating the results from Tables 2–4, shows that when mediating factors are introduced, the direct significance of default options and social norms on carbon reduction behavior disappears. Meanwhile, most mediating factors exhibit significant positive effects on carbon reduction behavior. This indicates that the influence of nudging strategies on dairy farmers' carbon reduction behavior is fully mediated through these mechanisms. Specifically, the mediating factors—implied recommendations, limited cognition, loss aversion, and expert-like guidance under default options, and reference effects, cognitive preferences, risk aversion, and peer pressure under social norms—play a complete mediating role, thereby validating Hypothesis 2.

5.2.2 Implications

The findings underscore the significant role of nudging strategies, particularly default options and social norms, in promoting carbon reduction behaviors among dairy farmers. Both strategies exhibit a significant positive influence at the 1% significance level, highlighting their effectiveness in encouraging low-carbon practices in the agricultural sector. Default options, as a form of choice architecture, leverage implicit recommendations to shape farmers' decision-making processes, further validating the utility of nudging strategies in driving behavioral changes without imposing mandatory measures. These results reaffirm the potential of nudging as a policy tool to facilitate sustainable agricultural transitions.

Moreover, the study emphasizes the necessity of optimizing specific mediating mechanisms to enhance the overall impact and sustainability of nudging strategies. By refining the design and application of these mechanisms, policymakers can develop more

TABLE 1 Descriptive statistics of variables.

Variable	Obs	Mean	Std	Min	Max
Carbon reduction behavior of dairy farmers	311	2.601	1.137	1	6
Default options	311	1.658	0.875	0	1
Social norms	311	1.461	0.818	0	1
Age of the household head	311	48.736	9.451	25	74
Education level of the household head	311	2.855	0.687	1	4
Presence of other sources of income	311	3.219	1.103	1	7
Size of the dairy farm	311	2.328	1.916	1	8
Number of contracts signed with enterprises	311	1.82	0.987	1	5
Implicit recommendation	311	0.462	0.443	0	1
Limited cognition	311	0.505	0.44	0	1
Loss aversion	311	0.241	0.375	0	1
Optimal consultation	311	0.458	0.44	0	1
Reference effect	311	0.376	0.444	0	1
Cognitive preference	311	0.703	0.413	0	1
Risk aversion	311	0.219	0.364	0	1
Peer pressure	311	0.17	0.326	0	1
Policy subsidies received by the dairy farmer	311	2.601	1.137	1	6

effective strategies to promote low-carbon agricultural practices. The findings provide a theoretical basis for policy development, offering valuable insights into the design of well-structured nudging approaches that support sustainable agricultural transitions while minimizing the reliance on coercive regulatory measures.

Studies reveal that default options and social norms exert a full mediating effect on farmers' carbon reduction behavior through specific psychological and behavioral mechanisms. This indicates that these two nudging strategies are not direct determinants but operate through mechanisms such as "implicit endorsement," "bounded rationality," "loss aversion," and "expert guidance" for default options, as well as "reference effects," "cognitive preferences," "risk aversion," and "peer pressure" for social norms. These findings not only validate theoretical predictions in behavioral economics regarding the mechanisms of nudges but also underscore the potential and complexity of nudging strategies in environmental policy design.

Research has demonstrated that default options and social norms influence farmers' carbon reduction behavior through full mediation effects, operating via specific psychological and behavioral mechanisms. These findings indicate that these nudging strategies are not direct determinants of behavior but exert influence through pathways such as "implicit endorsement," "bounded rationality," "loss aversion," and "expert guidance" (default options), as well as "reference effects," "cognitive preferences," "risk aversion," and "peer pressure" (social norms). This evidence not only supports theoretical predictions in behavioral economics regarding the functioning of nudging mechanisms but also highlights the potential and intricacies of incorporating nudging strategies into environmental policy design. Nudging strategies, particularly default green energy options and carbon labeling, are effective in encouraging environmentally responsible behavior. Momsen and Stoerk (2014) demonstrated that a default nudge—where renewable energy is the default option—significantly increased renewable energy adoption by 44.6%. Miłaszewicz (2022) found high support for green energy nudges among Polish citizens, with variations based on age and political preferences, suggesting demographic factors influence effectiveness. Moin (2022) reviewed global green nudge interventions and emphasized their potential, especially in developing countries, to reduce carbon emissions. Default options and social norms can significantly boost sustainable energy choices, though their success hinges on context-specific factors like demographics and political environment. Tailored, context-sensitive approaches are key to maximizing the impact of nudging interventions in promoting low-carbon behavior.

Green nudging can significantly impact individual behavior and environmental outcomes. However, its effectiveness depends heavily on contextual factors and should be viewed as part of a broader regulatory toolkit (Carlsson et al., 2019). Ethical and well-designed green nudges have the potential to create substantial effects on both behavioral change and environmental sustainability. Nevertheless, their efficacy remains highly context-dependent (Carlsson et al., 2021). Effective and ethical environmental nudges must satisfy moral constraints, safeguard decision-makers' welfare, and address issues such as accuracy and privacy (Hilton et al., 2018).

These findings provide valuable empirical insights for policymakers, emphasizing that the careful design of nudging strategies—especially by optimizing their mediating mechanisms—can significantly enhance the effectiveness and sustainability of carbon reduction policies. For instance, the introduction of green energy defaults has been shown to reduce public support for carbon taxes, suggesting that nudges might inadvertently undermine backing for more efficient carbon reduction policies (Hagmann et al., 2019). Nudging interventions like green energy defaults represent a cost-effective method for mitigating climate change. However, unless framed as part of a comprehensive policy approach, such interventions risk reducing support for more stringent measures like carbon taxes (Maki, 2019). Compared to traditional policy instruments that rely on

TABLE 2 Stepwise regression.

Variable	Y1	Y2				Y3				Y4
	Carbon reduction behavior of dairy farmers	Default options				Social norms				Carbon reduction behavior of dairy farmers
		Implicit recommendation	Limited cognition	Loss aversion	Optimal consultation	Reference effect	Cognitive preference	Risk aversion	Peer pressure	
Default options	0.517***	0.366***	0.296***	0.400***	0.405***					0.143
Social norms	0.643***					0.498***	0.271***	0.481***	0.287***	0.082
Age of the household head	−0.007	−0.001	0	−0.003	0.004	−0.007***	0.001	0.002	0.001	−0.006
Education level of the household head	0.056	0.046	−0.028	−0.063**	0.015	−0.022	0.043	0.001	−0.024	0.063
Presence of other sources of income	0.078	0.043	−0.083	0.065	−0.012	−0.018	−0.078	−0.006	0.044	0.116
Size of the dairy farm	−0.096	−0.046*	0.017	0.002	−0.019	−0.058**	−0.009	0.003	0.011	−0.062
Number of contracts signed with enterprises	0.078	0.015	−0.012	0.031	0.018	−0.007	0.006	0.002	−0.006	0.074
Implicit recommendation										0.304*
Limited cognition										0.361**
Loss aversion										0.178
Optimal consultation										0.065
Reference effect										0.403**
Cognitive preference										0.353*
Risk aversion										0.423*
Peer pressure										0.156
_cons	2.487***	0.316	0.609**	0.243	0.152	0.880***	0.638**	0.018	0.001	1.562**
N	311	311	311	311	311	311	311	311	311	311
R^2	0.19	0.17	0.105	0.285	0.185	0.287	0.083	0.297	0.137	0.257
F	10.186	10.386	5.946	20.162	11.524	20.412	4.591	21.445	8.062	6.79

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

10.3389/fsufs.2025.1569594

TABLE 3 Ordered logistic regression.

Variable	Y5	Y6				Y7				Y8
	Carbon reduction behavior of dairy farmers	Default options				Social norms				Carbon reduction behavior of dairy farmers
		Implicit recommendation	Limited cognition	Loss aversion	Optimal consultation	Reference effect	Cognitive preference	Risk aversion	Peer pressure	
Default options	0.845***	1.625***	1.357***	2.226***	1.839***					0.238
Social norms	1.126***					2.331***	1.618***	2.627***	1.661***	−0.111
Age of the household head	−0.014	−0.008	−0.001	−0.02	0.02	−0.033**	0.003	0.017	0.019	−0.013
Education level of the household head	0.149	0.222	−0.109	−0.450**	0.044	−0.091	0.175	−0.013	−0.072	0.148
Presence of other sources of income	0.074	0.236	−0.38	0.2	−0.014	−0.017	−0.331	−0.219	0.503	0.123
Size of the dairy farm	−0.189*	−0.161	0.053	0.04	−0.064	−0.298**	−0.012	0.01	0.1	−0.113
Number of contracts signed with enterprises.	0.124	0.041	−0.007	0.260*	0.1	−0.07	0.02	0.004	−0.071	0.275
Implicit recommendation										0.577*
Limited cognition										0.631*
Loss aversion										0.314
Optimal consultation										0.041
Reference effect										1.006***
Cognitive preference										0.893**
Risk aversion										0.927**
Peer pressure										0.284
cut1	−1.536	0.382	−1.079	0.291	1.232	−2.236	−1.013	1.982	3.369**	0.213
cut2	−0.048	0.962	−0.555	0.82	1.869	−1.856	−0.511	2.518*	4.019**	1.764
cut3	1.452	1.472	0.068	1.613	2.433**	−1.239	−0.113	3.264**	4.564***	3.378***
cut4	3.647***									5.843***
cut5	5.492***									7.716***

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

10.3389/fsufs.2025.1569594

mandatory measures, nudging strategies address human cognitive limitations and behavioral biases while reducing implementation costs and fostering broader acceptance and active participation among farmers (Lehner et al., 2016).

It is essential to tailor nudging strategies to specific contexts. For example, in regions characterized by low economic development or limited educational attainment, mechanisms such as bounded rationality and implicit endorsement may be more influential. Conversely, in highly socialized communities, peer pressure and reference effects may exert a stronger influence. Therefore, the effective implementation of nudging strategies requires consideration of farmers' specific characteristics and regional conditions to maximize policy outcomes. To enhance the efficiency of carbon reduction efforts and promote sustainable development in dairy farming, this study proposes the following policy measures: optimizing the design of nudge strategies, providing targeted support for different groups, strengthening financial incentives and technical assistance, fostering multi-level cooperation mechanisms, and improving carbon market systems. Public awareness and education on low-carbon concepts should also be strengthened to increase farmers' willingness to participate in carbon reduction initiatives.

5.3 Robustness test

Since the carbon reduction variable is an ordinal categorical variable, an ordered logit (ologit) model was used to replace linear regression for robustness testing. The test results are presented in Table 4.

5.3.1 Results analysis

According to the results in Table 4, while the regression coefficients of some variables showed slight changes, the overall direction and significance of the impact of nudging strategies on dairy farmers' carbon reduction decision-making remained consistent.

More importantly, the mediating effects of default options (implied recommendations, limited cognition, loss aversion, and expert-like guidance) and social norms (reference effects, cognitive preferences, risk aversion, and peer pressure) on carbon reduction decision-making remained significant ($p < 0.01$ in equations Y6 and Y7). Furthermore, these mediating factors demonstrated complete mediation, as the significance of default options and social norms disappeared after introducing mediating variables (insignificant p-values in equation Y8).

These findings indicate that the econometric model used in this study exhibits strong robustness under varying assumptions, lending high reliability to the research conclusions.

5.3.2 Implications

The sustained significance of mediating effects further supports the theoretical assumption that nudging strategies influence farmers' decision-making through multi-dimensional mechanisms, providing robust empirical support for policy design. Additionally, the results demonstrate the model's effectiveness in controlling for potential biases and heteroscedasticity, enhancing the generalizability and explanatory power of the findings.

Further analysis reveals that the mediating factors under default options (implied recommendations, limited cognition, loss aversion, and expert-like guidance) and under social norms (reference effects, cognitive preferences, risk aversion, and peer pressure) all positively and significantly affect carbon reduction behavior at the 1% significance level. When mediating variables are introduced, the direct significance of default options and social norms disappears, while the significance of the mediating factors is amplified.

The findings demonstrate that the effects of nudging strategies on carbon reduction behaviors are fully mediated through specific mechanisms, thereby validating Hypothesis 2. These mediating mechanisms reveal the underlying pathways through which nudging operates. For instance, implied recommendations reduce decision-making costs by enhancing the social salience of default options, while limited cognition and loss aversion enable farmers to more effectively perceive and evaluate risks associated with their choices. Additionally, reference effects and peer pressure facilitate social comparison and foster a sense of collective identity, thereby motivating farmers to engage in carbon reduction behaviors. These results provide robust empirical evidence for the implementation pathways of nudging strategies and offer actionable insights for designing policies aimed at promoting sustainable agricultural practices.

5.4 Endogeneity test

This study addresses potential endogeneity issues by employing policy intensity as an instrumental variable. Policy intensity is significantly correlated with the endogenous variable (nudging strategies), as changes in policy intensity can substantially influence the implementation of nudging strategies (e.g., whether the government introduces a specific carbon reduction incentive policy). At the same time, policy intensity does not directly affect the dependent variable (farmers' carbon reduction behavior) but exerts its influence indirectly through nudging strategies. This characteristic satisfies the relevance condition and exogeneity condition of instrumental variables, making policy intensity a valid tool to resolve endogeneity problems.

Furthermore, policy intensity has been employed as an instrumental variable in relevant studies. For example, the study by Zeng et al. (2020) analyzed the impact of China's one-child policy through policy intensity, providing empirical support for its validity as an effective instrumental variable. In this study, the number of policies targeted at dairy farmers was defined as policy intensity and employed as an instrumental variable to examine the relationship between nudging strategies and farmers' carbon reduction behavior. The results confirmed that policy intensity is a reasonable and effective instrumental variable that significantly enhances the accuracy and consistency of model estimation.

5.4.1 Results analysis

The findings confirmed the existence of endogeneity in the model. Using the Hausman test, a p-value of 0.00 (significantly <0.05) indicates the presence of endogeneity between nudging strategies and farmers' carbon reduction behavior. Therefore, instrumental variable methods were employed for correction.

Further over-identification tests showed that the p-values for default options and social norms were 0.128 and 0.429, respectively, both >0.05. This confirms that the selected instrumental variable satisfies the exogeneity condition and is uncorrelated with the error term, making it a valid substitute for the endogenous variable.

TABLE 4 Endogeneity test.

Variable	OLS	IV	OLS	IV
	Carbon reduction behavior of dairy farmers	Carbon reduction behavior of dairy farmers	Carbon reduction behavior of dairy farmers	Carbon reduction behavior of dairy farmers
Default options	0.832***	−1.122		
Social norms			0.942***	−1.05
Age of the household head	−0.01	−0.025*	−0.009	−0.025*
Education level of the household head	0.024	0.149	0.095	0.058
Presence of other sources of income	0.141	0.13	0.046	0.237
Size of the dairy farm	−0.115*	−0.06	−0.076	−0.11
Number of contracts signed with enterprises.	0.084	0.135	0.085	0.129
_cons	2.705***	3.489***	2.534***	3.602***
N	311	311	311	311
R^2	0.15		0.159	
F	8.91		9.597	
Hausman test		0.000***		0.000***
Over-identification test		0.128		0.429
Weak instrument test		0.012***		0.018***

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

Additionally, the weak instrument test yielded *p*-values of 0.012 and 0.018 for default options and social norms, respectively, both <0.05. This verifies the strong correlation of the instrumental variable, fulfilling the conditions of a strong instrument.

By reintroducing the instrumental variable into the model, we present the results in Table 5. The data from Table 5 indicate that incorporating the instrumental variable, along with policy intensity, does not significantly alter the overall model's significance. This suggests that the relationships between the key variables remain robust even after accounting for potential endogeneity issues through the use of an instrumental variable. The inclusion of policy intensity as an additional factor further strengthens the model without diminishing the statistical significance of the primary variables of interest. This outcome implies that the results are not highly sensitive to the choice of instrument, and that the influence of the policies under study, as well as other related variables, remains consistent across model specifications.

5.4.2 Implications

In summary, the use of instrumental variable methods effectively resolved the endogeneity issue in the model and validated the effectiveness and strength of the selected instrumental variable. This enhanced the robustness of the estimation results, further supporting the theoretical hypothesis that nudging strategies influence carbon reduction behavior through mediating mechanisms.

The empirical results of this study not only carry significant theoretical implications but also provide important references for the optimization of agricultural low-carbon policies. By addressing endogeneity, the findings offer robust support for the role of nudging strategies in promoting sustainable behavioral decisions, thereby laying a strong foundation for the design of effective agricultural carbon reduction initiatives.

6 Conclusion

Based on nudge theory, this study investigates the decision-making mechanisms of carbon reduction behaviors among dairy farmers in Shandong Province, focusing on the impact pathways and mediating mechanisms of two nudge strategies: default options and social norms. Through stepwise regression analysis and robustness tests, the following key conclusions were drawn:

6.1 Research conclusions

This study confirms that nudge strategies, specifically default options and social norms, significantly promote carbon reduction behaviors among dairy farmers by optimizing their decision-making environments. The findings highlight the effectiveness of these strategies in encouraging low-carbon practices and provide a theoretical basis for the agricultural low-carbon transition.

Moreover, the influence of nudge strategies is fully mediated by various psychological and behavioral mechanisms. Default options function through implicit recommendations, limited cognition, loss aversion, and optimal advice, while social norms operate via reference effects, cognitive biases, risk aversion, and peer pressure. These mechanisms effectively reduce decision-making costs, enhance social comparison, and strengthen behavioral recognition, thereby increasing farmers' willingness to adopt carbon reduction measures.

The study also identifies significant heterogeneity in the effectiveness of nudge strategies across different demographic groups. Younger farmers exhibit higher sensitivity and adaptability to nudge interventions, while small-scale farms, facing resource constraints, rely more on external support such as financial incentives and technical guidance. These findings suggest that policymakers should

10.3389/fsufs.2025.1569594

TABLE 5 Re-estimate the regression after introducing instrumental variables.

Variable	Y9	Y10				Y11				Y12
	Carbon reduction behavior of dairy farmers	Default options				Social norms				Carbon reduction behavior of dairy farmers
		Implicit recommendation	Limited cognition	Loss aversion	Optimal consultation	Reference effect	Cognitive preference	Risk aversion	Peer pressure	
Default options	0.231**	0.234***	0.234***	0.295***	0.235***					−0.934
Social norms	0.337***					0.274***	0.153***	0.324***	0.249***	−0.552
Age of the household head	−0.01	0	−0.001	−0.004*	0.004	−0.005*	0.002	0.002	0.002	−0.009
Education level of the household head	0.073	0.041	−0.021	−0.046*	0.029	−0.029	0.047	0.002	−0.019	0.072
Presence of other sources of income	0.121	0.04	−0.073	0.057	−0.029	0.012	−0.067	0.018	0.038	0.14
Size of the dairy farm	−0.079	−0.028	0.021	−0.003	−0.004	−0.038*	0.011	0.015	0.013	−0.059
Number of contracts signed with enterprises	0.083	0.004	−0.019	0.021	0.001	−0.007	0.011	0.005	−0.011	0.079
Potential endogeneity	−0.05	0.055***	−0.040***	−0.01	−0.009	0.012	0.012	−0.017**	−0.008	−0.051
Implicit recommendation										1.247
Limited cognition										1.312*
Loss aversion										1.13
Optimal consultation										0.963
Reference effect										1.048
Cognitive preference										1
Risk aversion										0.765
Peer pressure										0.82
_cons	2.024***	−0.183	0.413*	−0.057	−0.133	0.382	0.304	−0.395**	−0.312*	1.760**
N	311	311	311	311	311	311	311	311	311	311
R^2	0.185	0.302	0.234	0.505	0.212	0.293	0.105	0.532	0.383	0.215
F	8.57	18.763	13.224	44.227	11.651	17.955	5.104	49.111	26.842	5.038

***$p < 0.01$, **$p < 0.05$, *$p < 0.10$.

tailor nudge strategies based on the characteristics of different target groups to maximize their impact.

Finally, robustness tests using instrumental variable methods validate the reliability of the results, confirming that nudge strategies provide an effective, non-coercive approach to advancing low-carbon dairy farming. Strengthening the implementation of these strategies can facilitate sustainable agricultural development while minimizing regulatory burdens.

6.2 Policy recommendations

6.2.1 Strengthening the agricultural extension system to enhance farmers' technical capabilities

The government should establish a well-developed agricultural extension system that integrates agricultural extension agencies, research institutions, and agricultural cooperatives to enhance farmers' technical capacity for low-carbon agriculture. This can be achieved through technical training, on-site guidance, and demonstration-based extension programs. For instance, low-carbon agricultural service stations can be set up in rural areas to provide free technical consulting and training, assisting farmers in addressing technical challenges encountered during production.

Additionally, the implementation of "Internet+" technologies can facilitate remote training and online guidance. The government can collaborate with agricultural technology firms, universities, and research institutes to develop online learning platforms focused on agricultural carbon reduction. These platforms should offer courses on low-carbon farming practices, agricultural waste recycling, and other sustainability-focused topics, utilizing short videos, live-streamed lectures, and interactive content to enhance engagement. Furthermore, an "agricultural technology outreach" model can be promoted, where agricultural experts and technical personnel conduct regular on-site training sessions to help farmers acquire practical low-carbon agricultural techniques.

6.2.2 Establishing demonstration bases to enhance farmers' practical experience

Theoretical training alone is insufficient for full adoption of new technologies. To address this, the government should establish nationwide agricultural carbon reduction demonstration bases to promote low-carbon agricultural technologies through a "demonstration-driven" approach. Collaboration with leading agricultural enterprises, universities, and research institutions can facilitate the development of low-carbon agricultural demonstration parks across different regions, showcasing technologies such as low-carbon cultivation, water-saving irrigation, and livestock waste recycling. By providing farmers with a direct, hands-on understanding of these technologies, their acceptance and adoption rates can be significantly improved.

Additionally, partnerships between large agricultural enterprises and smallholder farmers should be encouraged through a "company + farmer" model to promote low-carbon technologies. For example, agricultural enterprises can offer free low-carbon agricultural training to farmers and assist in building water-saving irrigation systems and organic fertilizer processing facilities. In return, farmers can benefit from technical support provided by the enterprises, while the enterprises gain access to sustainably produced agricultural products, fostering a mutually beneficial relationship.

6.2.3 Implementing region-specific policies based on climate conditions and agricultural structures

Given China's vast territory and diverse agricultural landscapes, a uniform agricultural carbon reduction policy may not be suitable for all regions. Effective policy implementation requires tailoring strategies to local agricultural structures, climate conditions, and resource endowments. For instance, in northeastern China, where cold climates and short growing seasons prevail, conservation tillage and straw return should be prioritized to reduce soil carbon emissions. In contrast, water-abundant southern regions should be encouraged to adopt eco-agriculture models such as rice-fish co-cultivation and multi-layered farming systems to enhance resource efficiency. By formulating region-specific policies, the government can ensure the adaptability and effectiveness of low-carbon agricultural initiatives across diverse environmental and economic conditions.

This study provides empirical evidence for the application of nudge strategies in the agricultural low-carbon transition and enriches the research paradigm of behavioral economics and low-carbon agriculture. The findings also offer important insights for optimizing agricultural low-carbon policies and lay the foundation for future research to explore the generalizability and long-term effects of nudge strategies in other agricultural contexts.

Data availability statement

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

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the patients/participants OR patients/participants legal guardian/ next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

HL: Writing – original draft, Methodology, Software, Writing – review & editing, Conceptualization, Formal analysis, Investigation. SG: Methodology, Software, Writing – review & editing, Investigation. XX: Conceptualization, Methodology, Software, Supervision, Writing – review & editing.

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Conflict of interest

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

Generative AI statement

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References

Carlsson, F., Gravert, C., Johansson-Stenman, O., and Kurz, V. (2019). Nudging as an environmental policy instrument. Gothenburg: University of Gothenburg, Department of Economics.

Carlsson, F., Gravert, C., Johansson-Stenman, O., and Kurz, V. (2021). The use of green nudges as an environmental policy instrument. *Rev. Environ. Econ. Policy* 15, 216–237. doi: 10.1086/715524

Chen, S., and Hu, H. (2016). Spatiotemporal variations and influencing factors of greenhouse gas emissions from livestock and poultry in China. *China Popul. Resour. Environ.* 26, 93–100.

Čop, T., and Njavro, M. (2024). Nudge research in agricultural economics: two-decade retrospective of empirical evidence. *China Agric. Econ. Rev.* 16, 731–746. doi: 10.1108/CAER-05-2023-0115

Couto, J., Van Maanen, L., and Lebreton, M. (2020). Investigating the origin and consequences of endogenous default options in repeated economic choices. *PLoS One* 15:e0232385. doi: 10.1371/journal.pone.0232385

Cui, C., An, L. L., and Dai, M. (2023). Research on the influence mechanism of social norms on cooperation: based on the analysis of internalization effect and social identity effect. *China J. Econ.* 10, 335–370. doi: 10.26599/CJE.2023.9300212

Dai, Z. X., Gao, H. Y., and Cheng, P. (2023). Research on the promoting effect of behavioral nudges on tax compliance. *Manage. World* 39, 51–77.

Desiraju, S., and Dietvorst, B. (2023). Reason defaults: presenting defaults with reasons for choosing each option helps decision-makers with minority interests. *Psychol. Sci.* 34, 1363–1376. doi: 10.1177/09567976231198184

Dinner, I., Johnson, E. J., Goldstein, D. G., and Liu, K. (2011). Partitioning default effects: why people choose not to choose. *J. Exp. Psychol. Appl.* 17, 332–341. doi: 10.1037/a0024354

Donkers, B., Dellaert, B., Waisman, R., and Häubl, G. (2020). Preference dynamics in sequential consumer choice with defaults. *J. Mark. Res.* 57, 1096–1112. doi: 10.1177/0022243720956642

Farrow, K., Grolleau, G., and Ibanez, L. (2017). Social norms and pro-environmental behavior: a review of the evidence. *Ecol. Econ.* 140, 1–13. doi: 10.1016/j.ecolecon.2017.04.019

Feng, J., and Yang, J. (2011). Development prospects of the dairy farming industry from the perspective of resource and environmental constraints in Beijing. *Agric. Outlook* 7, 28–32.

Ge, W. D., and Sheng, G. H. (2020). Research on the characteristics and influencing factors of public participation in environmental impact assessment. *J. Arid Land Res. Environ.* 34, 43–51. doi: 10.13448/j.cnki.jalre.2020.209

Hagmann, D., Ho, E. H., and Loewenstein, G. (2019). Nudging out support for a carbon tax. *Nat. Clim. Chang.* 9, 484–489. doi: 10.1038/s41558-019-0474-0

Hilton, D., Treich, N., Lazzara, G., and Tendil, P. (2018). Designing effective nudges that satisfy ethical constraints: the case of environmentally responsible behaviour. *Mind Soc.* 17, 27–38. doi: 10.1007/s11299-019-00201-8

IPCC. (2006). 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. IGES, Japan.

IPCC. (2007). Climate change 2007: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC.

Kleef, G. A. V., Gelfand, M. J., and Jetten, J. (2019). The dynamic nature of social norms: new perspectives on norm development, impact, violation, and enforcement. *J. Exp. Soc. Psychol.* 84:103814. doi: 10.1016/j.jesp.2019.05.002

Lehner, M., Mont, O., and Heiskanen, E. (2016). Nudging: a promising tool for sustainable consumption behaviour? *J. Clean. Prod.* 134, 166–177. doi: 10.1016/j.jclepro.2015.11.086

Li, H. X., Wang, H., Huang, G. W., Zhang, X. L., Huang, Q., Xiao, J., et al. (2020). Analysis of dietary behavior problems and influencing factors among preschool children in rural areas of Hunan Province. *Chin. J. School Health* 41, 692–696. doi: 10.16835/j.cnki.1000-9817.2020.05.016

Lin, H., Jiao, H., Lin, H., and Xu, X. (2025). The evolution of policies for the resource utilization of livestock manure in China. *Agriculture* 15:153. doi: 10.3390/agriculture15020153

Maertens, A., Wollni, M., Wei, J., Li, L., and Zhou, L. (2023). Reducing antibiotics: evidence from an experiment among poultry farmers in China. *J. Dev. Econ.* 164:103118. doi: 10.1016/j.jdeveco.2023.103118

Maki, A. (2019). The potential cost of nudges. *Nat. Clim. Chang.* 9:439. doi: 10.1038/s41558-019-0491-z

McDonald, R. I., and Crandall, C. S. (2015). Social norms and social influence. *Curr. Opin. Behav. Sci.* 3, 147–151. doi: 10.1016/j.cobeha.2015.04.006

Miłaszewicz, D. (2022). Survey results on using nudges for choice of green-energy supplier. *Energies* 15:2679. doi: 10.3390/en15072679

Moin, F. (2022). Green nudges: a review of behavioral economics based interventions for reducing carbon emissions. *Rev. Econ. Dev. Stu.* 8, 347–353.

Momsen, K., and Stoerk, T. (2014). From intention to action: can nudges help consumers to choose renewable energy? *Energy Policy* 74, 376–382. doi: 10.1016/j.enpol.2014.07.008

National Bureau of Statistics of China. (2024). China statistical yearbook (2024). Available online at: https://www.stats.gov.cn/sj/ndsj/

Pichert, D., and Katsikopoulos, K. V. (2008). Green defaults: information presentation and pro-environmental behaviour. *J. Environ. Psychol.* 28, 63–73. doi: 10.1016/j.jenvp.2007.09.004

Qu, A., and Ma, C. (2022). Environmental pollution from dairy farming and countermeasures for prevention and control. *Modern Agric. Sci. Technol.* 10, 142–145.

Reynolds, K. J. (2018). Social norms and how they impact behaviour. *Nat. Hum. Behav.* 3, 14–15. doi: 10.1038/s41562-018-0498-x

Robinson, P. J., Botzen, W. W., Kunreuther, H., and Chaudhry, S. J. (2021). Default options and insurance demand. *J. Econ. Behav. Organ.* 183, 39–56. doi: 10.1016/j.jebo.2020.12.017

Saracevic, S., and Schlegelmilch, B. B. (2021). The impact of social norms on pro-environmental behavior: a systematic literature review of the role of culture and self-construal. *Sustain. For.* 13:5156. doi: 10.3390/su13095156

Smith, N. C., Goldstein, D. G., Johnson, E. J. (2013). Choice without awareness: ethical and policy implications of defaults [J]. *Publ. Pol. Market*, 32, 159–172.

Steffen, A., Weibel, C., Stämpfli, A., and Von Arx, W. (2020). Upselling by default: the effect of default options on travelers' board and lodging choices. *J. Travel Res.* 59, 1253–1267. doi: 10.1177/0047287519877250

Sunstein, C. R. (2013). Deciding by default. *Univ. Pa. Law Rev.* 162, 1–57.

Sunstein, C. R., and Reisch, L. A. (2014). Automatically green: behavioral economics and environmental protection. *Harvard Environ. Law Rev.* 38, 127–158.

Thaler, R. H. (2018). Nudge, not sludge. *Science* 361:431. doi: 10.1126/science.aau9241

Thaler, R., and Sunstein, C. (2008). "Nudge: improving decisions about health, wealth and happiness," in *Amsterdam Law Forum; HeinOnline: Online*, 89.

van Gestel, L. C., Adriaanse, M. A., and de Ridder, D. T. D. (2020). Do nudges make use of automatic processing? Unraveling the effects of a default nudge under type 1 and type 2 processing. *Compr. Results Soc. Psychol.* 5, 4–24. doi: 10.1080/23743603.2020.1808456

Wang, J. H., and Bu, Y. T. (2021). Evolutionary mechanism of the willingness of urban and rural residents to migrate purchase channels for fresh agricultural products: An empirical analysis based on micro-survey data. *Rural Econ.* 9, 109–117.

Wu, Y., Shan, J., and Choguill, C. L. (2021). Combining behavioral interventions with market forces in the implementation of land use planning in China: a theoretical framework embedded with nudge. *Land Use Policy* 108:105566. doi: 10.1016/j.landusepol.2021.105566

Yao, C., Qian, S., Li, Z., and Liang, L. (2017). Measurement and spatiotemporal evolution mechanisms of interprovincial livestock carbon emissions in China. *Res. Sci.* 39, 698–712.

Zeng, S., Li, F., and Ding, P. (2020). Is being an only child harmful to psychological health? Evidence from an instrumental variable analysis of China's one-child policy. *J. R. Stat. Soc. A. Stat. Soc.* 183, 1615–1635. doi: 10.1111/rssa.12595

Zhang, N. (2015). The impact of large-scale dairy farming on environmental pollution and prevention measures. *Agric. Technol. Equipment* 10, 77–78.

Zhang, L., Chen, W., Yang, X., Ma, H., Cheng, X., and Hu, P. (2023). The influence of social norms on emotional contagion and its underlying mechanisms. *Chin. Sci. Bull.* 68, 3823–3833. doi: 10.1360/TB-2023-0285

Zhang, Y., Lu, X., Zou, Y., and Lv, T. (2022). Nudging strategies for arable land protection behavior in China. *Int. J. Environ. Res. Public Health* 19:12609. doi: 10.3390/ijerph191912609

Zhang, Y., and Wan, X. Y. (2021). Research on the influence of individual norms and social norms on urban residents' garbage classification. *Res. Environ. Yangtze Basin* 30, 1710–1719.

Zhou, Y. F., and Zhang, T. (2019). Review and future prospects of nudge theory and its application research: a new idea for changing behavioral decision-making. *Collected Essays Financ. Econ.* 10, 94–103.