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Research article

Decoding the psychological, behavioral, and environmental drivers of farmers' willingness to participate in rural household waste source separation: A SEM analysis of policy influence, attitudinal changes, and perceived risks

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Abstract: [Purpose] Our purpose of this study is to construct a "psychological-behavioral-environmental" analytical framework to explore the influencing mechanism of farmers' participation in waste classification. [Methods] An empirical analysis was conducted through questionnaires and structural equation modeling to reveal the significant effects of behavioral attitudes, Subjective norm, and perceived values on farmers' willingness to participate. [Findings] The results showed that (1) attitude toward behavior, Subjective norm, perceived behavioral control, perceived value, perceived risk, and past experiences have a significant positive influence on farmers' willingness to participate in source separation and reduction of rural household waste. The path coefficient of perceived value was 0.78, which is an important factor influencing willingness to participate. (2) Attitude toward behavior plays a significant mediating role in the relationship between perceived value, perceived risk, past experience, and willingness to participate. (3) Environmental regulation has a negative moderating effect on the relationship between behavioral attitudes and willingness to participate, indicating that there is a formalization problem in the current policy environment and that over-reliance on administrative intervention may not be conducive to the formation of endogenous motivation of farmers. (4) The willingness to participate was stronger among farmers with higher education and higher household income levels, while the older group showed lower motivation to participate due to lack of classification knowledge and stereotyped habits. [Originality/value] Effective enhancement of

farmers' participation in garbage classification requires the integration of cognitive reinforcement, behavioral motivation, conscious awareness cultivation, and institutional innovation.

Keywords: farmers' willingness; rural domestic waste; source separation and reduction; perceived value; environmental regulation

1. Introduction

China's rural revitalization has elevated farmers' living standards; however, rural domestic waste management remains a critical bottleneck for sustainable development. The annual waste output exceeds 300 million tons, with 70% disposed through mixed collection and basic landfills, achieving less than 15% resource utilization. This exacerbates environmental challenges, including "garbage-encircled villages" [1], soil contamination, and water eutrophication while threatening farmers' health and ecological safety. Despite improved rural habitats [2], as shown in Figure 1, the amount of trash is on a continuous upward trend (2018–2024 data). The governance paradox of "government enthusiasm versus farmer indifference" in waste sorting persists, requiring an urgent resolution to achieve modern environmental governance [3]. The current research highlights the need for behavioral interventions and technological solutions to bridge this implementation gap [4].

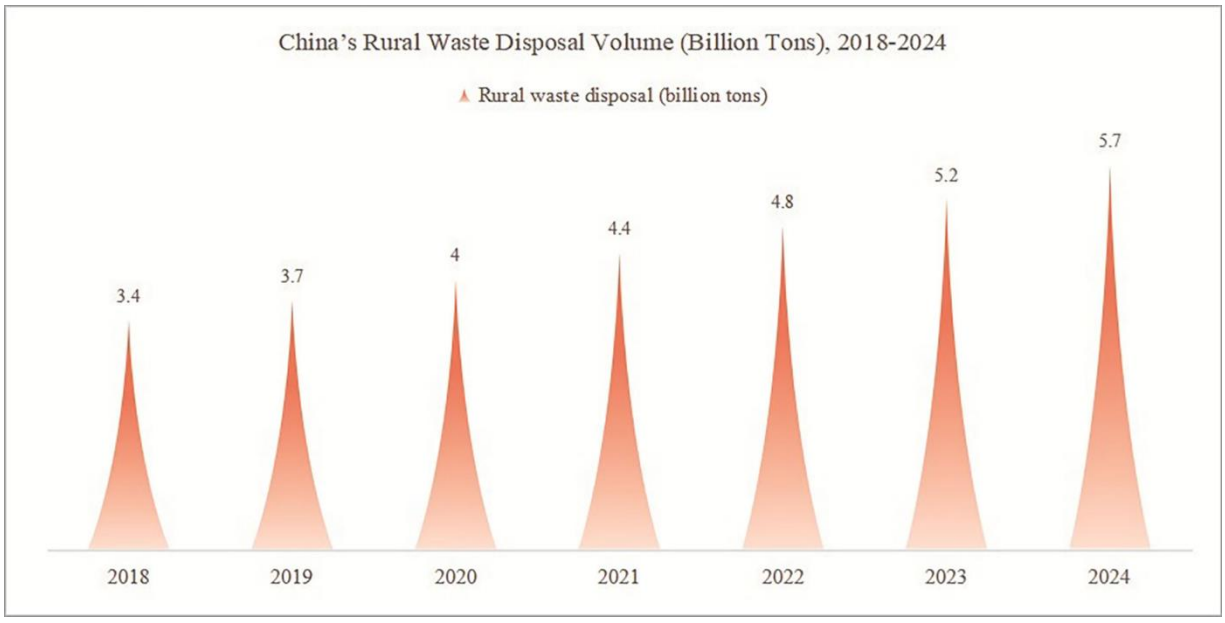

Figure 1. Data on rural waste disposal in China.

Research on rural household waste classification has revealed diverse methodological approaches and key findings [5]. For instance, Wang employed fuzzy-set qualitative comparative analysis to identify multi-factor synergies in behavioral mechanisms, offering governance pathways through factor combinations. Su's analysis [6] framework demonstrated that hierarchical rule configurations in policy systems drive collective action through institutional interactivity and integrity [7]. Gao developed an affective event theory framework using multilevel linear modeling to prove

informational policy tools enhance classification willingness through direct mechanisms and negative emotional expectation pathways [8]. Song's externality theory framework found that institutional constraints reduce the willingness to behave more effectively than social norms [9]. Chen revealed differentiated impacts of guidance-based versus reward-punishment environmental regulations mediated through environmental cognition, value perception, and social trust chains [10]. Zhu introduced digital governance theory, demonstrating digital literacy strengthens waste sorting through information acquisition and environmental cognition pathways, proposing a "literacy-cognition-behavior" empowerment model.

Despite methodological diversity, four theoretical gaps persist: (1) Fragmented psychological mechanisms; most researchers prioritize external contextual factors over systematic integration of internal psychological variables, particularly lacking comprehensive testing of attitudes' mediating role in behavioral willingness formation. (2) Static policy conceptualization; research treats policies as fixed contextual variables than dynamic moderators between psychological variables and behavior, resulting in imprecise policy design insights. (3) Limited interdisciplinary integration; the localized application of the Theory of Planned Behavior (TPB) remains confined to urban contexts, with inadequate incorporation of rural-specific variables like "past experience" and "perceived value" that could enhance model explanatory power. (4) Source-level neglect; researchers predominantly address waste management processes than tracing problems to their origins in waste generation patterns, overlooking critical upstream interventions.

The remainder of this paper is organized as follows: First, based on the TPB framework, we introduce perceived value, perceived risk, and past experience to construct a three-dimensional analysis model of "psychology-behavior-environment", which breaks through the limitations of traditional theories on the explanatory power of rural situations. This model overcomes the limitations of traditional theories in explaining the rural context. Then, through 442 questionnaire surveys covering multiple regions of China, we adopted SEM and a bootstrap intermediation test to systematically analyze the direct and mediating effects of behavioral attitudes and Subjective norm on the willingness to categorize and innovatively introduce the analysis of the moderating effect of environmental regulation.

2. Literature review and research hypotheses

2.1. Literature review

Research on rural household waste management has evolved within a multi-dimensional "psychological-behavioral-institutional" framework, examining individual, social [11], and policy drivers of farmers' participation. Researchers have increasingly adopted theoretical lenses such as the Theory of Planned Behavior (TPB), risk perception theory, and policy instrument theory to explain farmers' waste sorting behavior, though significant gaps remain in integration and contextual adaptation. Various theoretical perspectives have been employed to investigate farmers' waste-sorting behavior, as detailed in Table 1.

From the perspective of the Theory of Planned Behavior (TPB), researchers have identified behavioral attitudes, Subjective norm, and perceived behavioral control as key predictors of waste sorting intention [12]. Zhu et al. validated this framework in southern Jiangsu, showing that perceived behavioral control, such as access to sorting facilities, had the strongest effect on participation

willingness. However, the traditional TPB model often overlooks rural-specific contextual factors such as social capital and digital literacy [13]. Zhang et al incorporated "digital literacy" into TPB, demonstrating that digitally proficient farmers were 28% more willing to sort waste due to improved environmental knowledge access. Similarly, Chen and Leng [14] supported a sequential path of "digital access → improved pollution risk perception → attitude change → higher willingness". Jia and Zhao [15] further expanded TPB by introducing "past experience", showing that successful prior participation strengthened the influence of Subjective norm. Despite these advances [16], TPB applications remain limited by sample bias toward eastern China and reliance on cross-sectional data [17].

Table 1. Theoretical perspectives on farmers' waste sorting behavior.

Theoretical Perspective	Core content	Method	Authors (year)
Theory of Planned Behavior (TPB)	Examines the impact of attitudes, Subjective norm, and perceived behavioral control on sorting intention and behavior. Expansions include digital literacy and past experience.	Questionnaire survey, Structural Equation Modeling (SEM), Regression models	Zhu et al. (2022); Zhang et al. (2023); Chen & Leng (2025); Jia & Zhao (2020)
Risk Perception Theory	Focuses on how subjective assessment of threats (health, environmental) influences participation willingness and behavior	Logistic regression, Mediated effects models, Survey data	Van Fossen et al. (2022); Shi & Yu (2024); He et al. (2022); Chen et al. (2023).
Policy Instrument Theory	Evaluates the effectiveness of different policy tools (command-and-control, economic incentives, informational) on shaping behavior.	Case studies, Evolutionary game theory, Comparative analysis, fsQCA	Qu & Zhao (2022); Zhou et al. (2024); Zeng (2024); Wei & Ma (2022); Zhu & Qin (2023)
Social Capital & Institutional Theory	Explores the role of social networks, trust, village norms, and formal institutions in facilitating or hindering collective action in waste management.	Ordered Probit model, Nested institutional analysis, Case study	Zhang et al. (2022); Jiang (2023); Su & Mo (2024)

Risk perception theory offers another lens, emphasizing farmers' subjective evaluation of threats from improper waste disposal. Shi and Yu [18] confirmed that soil pollution risk perception positively influenced willingness, especially among low-income households. However, academic debate persists regarding the pathways through which risk perception operates: He et al. [19] argued for a direct effect, while Chen et al. [20] identified attitude as a mediator. Ng et al. [21] attributed these discrepancies to

regional variations; eastern farmers focus on ecological risks, whereas western farmers prioritize immediate health threats. Key gaps include unidentified risk perception thresholds and neglected social filtering of risk information.

Policy instrument theory categorizes interventions as command-and-control, incentive-based, or punitive. Qu and Zhao [22] found that mandatory standards raised sorting accuracy but increased costs due to farmer resistance. In contrast, incentive tools proved more sustainable: Zhou et al. [23]. documented Zibo's "Digital Phoenix" platform, where point-based rewards stabilized participation at 80%. Zeng [24] showed that combining material incentives with social recognition increased sustained participation by 33%. Punitive tools remain contentious; Wei and Ma [25] found moderate fines effective, but Zhu and Qin [26] observed a "broken windows effect" in low-income areas. Studies highlight the importance of cultural context [27], targeted education [28], infrastructure quality, and leadership [29] in shaping policy effectiveness.

The literature provides a multidimensional perspective for understanding farmers' participation in garbage-sorting behavior, but it needs to be deepened in terms of theoretical depth and policy operationalization. The major limitations are the following three aspects: (1) Insufficient theoretical integration and lack of interactive analysis of psychological variables and institutional elements. (2) The methodology favors linear regression and ignores the multifactor group effect and dynamic evolution laws. (3) Homogenization of policy recommendations without designing differentiated paths for heterogeneous rural groups. To overcome the shortcomings of the literature, this study fills this gap through three breakthroughs: (1) Constructing a three-dimensional framework of "psychology-behavior-environment" and incorporating the moderating variables of environmental regulation. (2) SEM and bootstrap mediation tests were adopted to reveal the transmission mechanism of attitude among value, risk, and willingness. (3) The adaptive path of "flexible governance + digital empowerment" is proposed to provide a theoretical basis for the precise implementation of rural waste management.

2.2. Research hypothesis

2.2.1. Assumptions about the TPB

Behavioral attitude, as an individual's evaluative [30] stance toward specific actions, significantly predicts the willingness to participate in rural waste source separation. Rooted in the Theory, farmers' positive attitudes emerge from their perceived benefits of waste sorting, including economic gains, environmental improvements [31], and moral satisfaction. When recognizing these multidimensional values (economic returns for households, community-wide ecological enhancements, and ethical fulfillment), farmers develop stronger behavioral intentions This attitude-to-willingness conversion manifests as active rule compliance, knowledge acquisition, and peer advocacy for waste separation practices. Furthermore, heightened value perceptions amplify proactive engagement [32], transforming participants into voluntary advocates of waste classification initiatives. As a result, we propose the following hypothesis:

Hypothesis 1. Attitude toward behavior has a positive effect on farmers' willingness to participate in source separation and the reduction of rural domestic waste.

Subjective norm, perceived social pressures and expectations influencing behavioral choices, significantly shape rural households' willingness to participate in waste source separation [33].

When farmers sense support and normative expectations from family members, neighbors, or village officials [34], they internalize waste sorting as socially desirable conduct, strengthening their intent to participate. From a social psychology perspective, individuals align themselves with group norms to maintain their social identity and belonging. Rural communities that frame waste sorting as a responsible [35], respected practice create a normative atmosphere that motivates compliance. Participation is further amplified through herd mentality and imitation behaviors triggered by peers' active engagement [36], as well as demonstration effects where visible benefits (e.g., economic rewards and social recognition) for early adopters incentivize emulation. Observing successful cases reinforces the perceived feasibility and value of waste sorting [37], thereby enhancing willingness to do so. As a result, we propose the following hypothesis:

Hypothesis 2. Subjective norm has a positive effect on farmers' willingness to participate in source separation and reduction of rural domestic waste.

Perceived behavioral control (PBC) [38], an individual's confidence in their ability to execute waste source separation, critically shapes farmers' willingness to participate. When farmers possess adequate knowledge [39], skills, and resources (e.g., sorting facilities and informational materials), they perceive the behavior as feasible and manageable, enhancing their intent [40]. PBC intertwines with self-efficacy; belief in task competence increases behavioral persistence. Resource availability reduces perceived effort, whereas value compensation (e.g., economic returns and environmental benefits) reinforces perceived controllability and the worthiness of participation [41]. Government policies further strengthen PBC by clarifying guidelines and support mechanisms [42], boosting farmers' confidence in overcoming implementation barriers, though participation requires time/energy investment [43], processes and demonstrable benefits mitigate perceived costs [44]. As a result, we propose the following hypothesis:

Hypothesis 3. Perceived behavioral control has a positive effect on the willingness of farmers to participate in rural household waste reduction participation at source.

2.2.2. Assumptions related to perceived value

Perceived value, an individual's comprehensive evaluation of benefits based on subjective judgment and experience, significantly enhances farmers' willingness to engage in rural waste source separation [45]. Farmers prioritize practical benefits (material gains, environmental improvements, and moral incentives) when assessing participation value [46]. As rational actors, they weigh economic returns (e.g., reduced disposal costs) and social recognition [47], which collectively drive participation intent. Environmental awareness further amplifies this effect; clearer pollution perceptions correlate with stronger behavioral commitment.

Social capital and constraints critically shape participation dynamics [48]. Social norms (village regulations, peer supervision) and policy frameworks create external pressures, while trust and collective norms mitigate "free-riding" tendencies by fostering cooperation [49]. Demographic factors (age and education) and household characteristics influence behavioral adoption, but intrinsic motivations, such as environmental responsibility, often outweigh external constraints.

Cost-benefit trade-offs determine sustained engagement. farmers balance time and energy investments against tangible rewards (resource recovery benefits) and intangible gains (community status) [50]. Demonstration effects emerge when early adopters' successes trigger peer imitation [51], thereby creating competitive participation loops. This value-driven cycle reinforces collective action

and transforms individual willingness into community-wide practice [52]. As a result, we propose the following hypothesis:

Hypothesis 4. Perceived value has a positive effect on the willingness of farmers to participate in source separation and reduction of rural domestic waste.

Farmers' perceived value of waste source separation directly shapes their behavioral attitudes toward the activity. Recognizing multidimensional benefits (i.e., material gains, ecological improvements, and alignment with sustainable development), farmers develop more positive attitudes and internalize waste sorting as both a responsibility and habitual practice [53]. This attitudinal shift drives proactive engagement: Farmers dedicate time to learning classification rules, comply with guidelines, and advocate its benefits to others. Attitude formation transcends material incentives, rooted in expectations for rural environmental revitalization and ethical alignment with sustainability. Furthermore, positive attitudes enhance participation initiative and transform waste sorting into a self-reinforcing social norm [54], and perceived value operates through dual pathways: Directly boosting participation willingness and indirectly by fostering positive attitudes that amplify intent. When farmers acknowledge the intrinsic and extrinsic value of waste reduction, their attitudinal commitment becomes a catalyst for sustained behavioral engagement. As a result, we propose the following hypothesis:

Hypothesis 5. Perceived value has a positive effect on farmers' attitudes toward participation in source separation and reduction of rural domestic waste.

Attitude toward behavior, as the degree of positive or negative evaluation an individual holds toward a behavior, plays a key mediating role in the relationship between perceived value and willingness to participate [55]. When rural households perceive the value of source separation and the reduction of rural household waste, they will first form a positive attitude toward the activity, which will then lead to their willingness to participate. From the perspective of the mechanism of action, perceived value enhances the environmental protection cognitive level of rural households and enhances their willingness and behavior in domestic waste classification [56]. Positive attitudes will further stimulate the willingness of farmers to participate in the work of waste classification, so that they are more actively involved in the work of waste classification and are willing to make more efforts to maintain a good rural environment. This suggests that attitudes toward behavior have an impact on willingness to participate by influencing perceived value [57]. As a result, we propose the following hypothesis:

Hypothesis 6. Attitude toward behavior plays a mediating role between perceived value and willingness to participate.

2.2.3. Assumptions related to perceived risk

Perceived risk, defined as an individual's subjective assessment of potential threats, significantly influences farmers' willingness to engage in rural household waste source separation and reduction [58] Farmers' participation intent is stimulated when they perceive risks associated with improper waste management (e.g., environmental degradation and health hazards) and recognize their role in mitigating these threats through proactive involvement. Notably, subjective risk perception, often diverging from objective risks, plays a dominant role in decision making. Individuals with heightened risk awareness tend to seek more information to minimize uncertainties [59], a behavior validated by van Fossen et al., who found that perceived risk strongly correlates with participation attitudes. Farmers' decisions are shaped not only by livelihood considerations, but also by external risk constraints, necessitating a dual analysis of internal and external risk perceptions to comprehensively

understand their behavioral mechanisms.

Environmental deterioration and heightened ecological awareness further amplify the risk sensitivity of farmers. Living in polluted environments, farmers increasingly recognize the harm of inaction, driving active participation in waste reduction to mitigate negative impacts [60]. Enhanced environmental education and social advocacy elevate pollution risk awareness and transform waste classification into a strategic response to the perceived threats. Thus, we propose the following hypothesis:

Hypothesis 7. Perceived risk has a positive effect on the willingness of farmers to participate in source separation and reduction of rural domestic waste.

Farmers' perceptions of the risks associated with source separation and reduction of rural domestic waste will lead to the formation of positive attitudes [61]. When farmers realize that poor waste separation may lead to a series of problems, they attach importance to it and develop positive attitudes. farmers will take the initiative to learn about waste separation, put out waste in strict accordance with classification standards, and actively participate in waste separation publicity activities organized by the village [62]. Positive attitudes stem from farmers' awareness of risks and protection of their own and their family's health, which in turn safeguards the perception and health of the living environment and forms good living habits and attitudes. As a result, we propose the following hypothesis:

Hypothesis 8. Perceived risk has a positive effect on farmers' attitudes toward participation in source separation and reduction of rural domestic waste.

When farmers perceive the risk of rural domestic waste classification and reduction at the source, they will first form an attitude towards waste classification [63], which will then affect their willingness to participate. In the process of implementing domestic waste classification in villages, the setting of various reward and punishment mechanisms has an important impact on the classification behavior of farmers. Based on positive attitudes, farmers will be more willing to participate in the activities of rural domestic waste classification and reduction at source [64], actively cooperate with the village's waste classification work, and actively supervise the waste classification behavior of others. Behavioral attitudes play a moderating and transforming role between perceived risk and willingness to participate, transforming farmers' perceptions of risk into actual participation behavior. As a result, we propose the following hypothesis:

Hypothesis 9. Attitude toward behavior plays a mediating role between perceived risk and willingness to participate.

2.2.4. Assumptions related to past experiences

Past experiences act as cognitive anchors that shape farmers' willingness to participate in rural household waste-source separation and reduction. Individuals with prior involvement in similar activities tend to replicate past behaviors using these experiences as critical references for future decisions [65]. In waste management, farmers' historical exposure to waste-related challenges and their knowledge levels significantly influence their engagement [66]. Successful past participation reinforces behavioral intent as positive outcomes strengthen confidence in future actions. For instance, Zeng et al. demonstrated that prior experiences shape attitudes and willingness to revisit ecotourism sites [67], whereas Zhen et al. found that past accident experiences altered miners' safety behaviors through attitude mediation. Similarly, farmers' satisfaction with their previous waste management efforts directly correlates with more positive attitudes and a higher likelihood of sustained participation.

Positive experiential feedback transforms participation into a habitual responsibility [68]. When farmers observe tangible improvements in village environments and quality of life from past efforts, they internalize waste sorting as meaningful and achievable. This self-efficacy, coupled with visible environmental benefits, fosters identity-driven engagement and transforms participants into active advocates. As David et al. noted, successful waste management practices create self-reinforcing cycles in which behavioral commitment evolves into community norms. Such feedback mechanisms enhance farmers' intuitive understanding of the value of waste separation, solidifying their willingness to persist and promoting these activities [69]. As a result, we propose the following hypothesis:

Hypothesis 10. There is a positive effect of past experiences on the willingness of farmers to participate in source separation and reduction of rural domestic waste.

Farmers' past experience in source separation and reduction of rural domestic waste affects their attitudes. If farmers have had the experience of successfully participating in waste separation and achieving good results, farmers will have a more positive attitude towards waste separation. Personal experience will make farmers realize the importance and feasibility of garbage classification, thus forming a positive attitude towards garbage classification [70]. Farmers will be more active in learning the knowledge of garbage classification, pay attention to the policy and dynamics of garbage classification, and be willing to practice the concept of garbage classification in their daily life. Furthermore, the positive attitude will also influence the farmers around them and lead them to participate in waste separation together. Past experiences become an important foundation for farmers to form positive attitudes, so that farmers recognize the value and significance of garbage classification from the bottom of their hearts. Thus, we propose the following hypothesis:

Hypothesis 11. There is a positive effect of past experiences on farmers' attitudes toward participation in source separation and reduction of rural domestic waste.

Behavioral attitudes play a key mediating role between farmers' past experiences and willingness to participate. When farmers have had positive past experiences, they will first form positive attitudes toward source separation and reduction of rural domestic waste, which in turn will lead to their willingness to participate. Based on the positive attitude, farmers will be more willing to participate in subsequent waste separation activities, and are willing to share their experiences and insights with other farmers' Behavioral attitudes play a connecting and transforming role between past experiences and willingness to participate, transforming past experiences into actual motivation to participate. As a result, we propose the following hypothesis:

Hypothesis 12. Behavioral attitudes play a mediating role between past experiences and willingness to participate.

2.2.5. Assumptions about environmental regulation

Environmental regulation serves as a critical external moderator that shapes farmers' willingness to participate in rural household waste source separation and reduction. Government policies on waste management, when perceived positively, enhance participation intention by framing waste sorting as a civic responsibility and a means to obtain tangible benefits. As the public goods theory highlights in the research [71], the externality-driven "free-riding" problem of rural waste.

In addition, environmental regulation can regulate farmers' willingness to participate by influencing their expectations of the costs and benefits of their behavior. Reasonable environmental regulation can reduce the cost of farmers' participation in waste classification and increase their benefit expectations,

thus enhancing their willingness to participate. As a result, we propose the following hypothesis:
Hypothesis 13. Environmental regulation has a significant moderating effect on the willingness relationship.

Based on the above analysis, this study constructs a theoretical model of farmers' willingness to participate in source separation and reduction of rural household waste, as shown in Figure 2. The model takes farmers' willingness to participate in source separation and reduction of rural household waste as an endogenous latent variable, and Subjective norm, behavioral attitudes, perceptual behavioral control, perceived value, perceived risk, and past experience as an exogenous latent variable, among which behavioral attitudes variable has a significant influence on the relationship between perceived risk, perceived value, and past experience. Experiences play a mediating role in the relationship between perceived risk, perceived value, and past experiences on willingness to participate, and environmental regulation plays a moderating role in the relationship between behavioral attitudes on willingness to act.

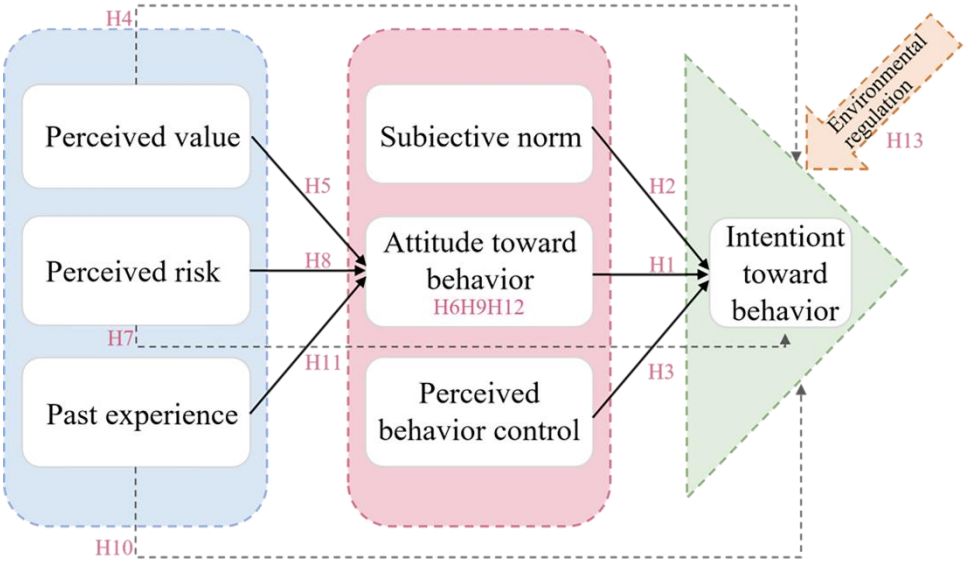

Figure 2. Theoretical model of farmers' willingness to participate in source separation and reduction of rural domestic waste bibliography.

3. Methodology

3.1. Questionnaire design and description of variables

The questionnaire consisted of three parts. The first part described the background and purpose of the survey. The second part involved the collection of demographic information. The third part was designed around a theoretical model of farmers' willingness to participate in source separation and reduction of rural household waste, including 28 measurement items in eight dimensions.

The variable description in this paper adopted Likert's 5-level representation to quantitatively set the explanatory variables and core explanatory variables, and the setting and measurement of variables are shown in Table 2. The explanatory variable in this study was the willingness of farmers to

participate in source separation and reduction of rural household waste, and there were four question sets. The core of farmers' participation in source classification and reduction of rural household waste was to promote the improvement of the rural environment and the effective use of resources through source classification and reduction treatment, combined with policy guidance and villagers' conscious actions. Including attitude toward behavior, Subjective norm, perceived behavior control, perceived value, perceived risk, past experiences, and environmental regulation, we set to 3-4 questions for each dimension to measure the explanatory variables.

3.2. Data collection

To ensure the data exhibited sufficient differences, diversity, and representativeness, we adopted a mixed-method approach, integrating online and offline survey techniques to carry out the research. The online survey was mainly distributed online based on the Questionnaire Star platform, and a snowballing approach was adopted to expand sample collection. The survey was conducted from February 5, 2024 to February 15, 2024 in multiple locations. We received 683 questionnaires in total. After screening out invalid ones, 442 valid questionnaires remained. The effective rate of the recovered samples reached 64. 7%. The respondents' basic characteristics are listed in Table 2.

Table 2. Basic characteristics of respondents.

Variant	Norm	Frequency	Percentage
Distinguishing between the sexes	Men	161	36.4%
	Women	281	63.6%
(a person's) Age	Under 18	22	5.0%
	18-30 years	196	44.3%
	31-45 years	91	20.6%
	46-60 years	92	20.8%
	60 years and over	41	9.3%
Education attainment	Uneducated	34	7.7%
	Secondary schools	52	11.8%
	Junior high school	56	12.7%
	High school/secondary school	83	18.8%
	College and above	217	49.1%

The distribution of the survey sample included 161 males (36.4 %) and 281 females (63.6 %), which differs from the gender structure of rural labor forces in China (where males typically account for ~55% of agricultural labor, per national rural development statistics). The age of the respondents was mainly concentrated between 18–30 years old, accounting for 44.3%, while people over 31 years old accounted for 41.4%; notably, the elderly group (over 60 years old) accounted for only 9.3%, lower than the 18.7% proportion of rural elderly population in China. In terms of education, 49.1% of

respondents had a college degree or above, far higher than the national rural population's college education rate of ~12%, indicating a rejuvenation and higher-education bias in the sample.

3.3. Research methodology

The theoretical model constructed in this study had complex path relationships, and there were unavoidable subjective errors in the measurement of latent variables. Thus, SEM was introduced for empirical analysis. SEM includes a measurement model reflecting the relationship between latent and measurable variables and a structural model reflecting the structural relationship among latent variables. In this paper, attitudes toward behavior were used as mediating variables, and the relationship between perceived value, perceived risk, and past experiences and intention toward behavior is illustrated using the following equation:

$$Y=cX+e_1 \tag{1}$$

$$M=aX+e_2 \tag{2}$$

$$Y=c'X+bM+e_3 \tag{3}$$

Equations (1) and (2) are the measurement models, and Eq (3) represents the structural model. We included seven latent variables (intention toward behavior, attitude toward behavior, Subjective norm, perceived behavior control, past experiences, perceived risk, and perceived value) and 28 observed variables.

4. Discussion

4.1. Convergent validity

The loadings and AVE of each observation item can be used to evaluate the degree of correlation between individual measurement items in a given measurement model. The higher the value of the loadings of each observation item, the higher the commonality in measuring the latent variables, and the better the convergent validity of the measurement model.

From Table 3, we can see that the standardized loading coefficients of each factor variable are greater than 0.5, indicating that the measurement variables meet the requirements of the factor, and passed the significance test ($P < 0.05$). It can be determined that it has enough variance interpretation rate, and the performance of each variable can be shown on the same factor. The AVE values of perceived behavior control, perceived risk, and past experience are all greater than 0.5, and the CR values are all greater than 0.7, which indicates that all three variables have good convergent validity and combined reliability.

Table 3. Convergent validity and combined reliability of the variables.

Dimension	Subject	Estimate	AVE	CR	KMO and Bartlett's test	Cronbach'sα value
Attitude toward behavior	A1	0.541	0.4248	0.6856	0.657	0.685
	A2	0.660				
	A3	0.739				
Subjective norm	S1	0.549	0.4003	0.6648	0.649	0.664
	S2	0.641				
	S3	0.699				
Perceptual-behavioral control	P1	0.664	0.5851	0.7352	0.500	0.716
	P2	0.854				
Perceived value	V1	0.697	0.4017	0.7279	0.768	0.763
	V2	0.623				
	V3	0.593				
	V4	0.599				
Perceived risk	R1	0.729	0.6459	0.7835	0.500	0.777
	R2	0.872				
Past experience	E1	0.804	0.5625	0.7930	0.690	0.783
	E2	0.779				
	E3	0.659				
Intention toward behavior	I1	0.653	0.4711	0.7804	0.793	0.804
	I2	0.651				
	I3	0.713				
	I4	0.726				

In a practical study, if the AVE is slightly lower than 0.5, but the CR is still higher than 0.6, and the factor loadings are significant ($P < 0.05$), the model can be accepted in conjunction with theoretical implications. For the latent variables with AVE values below 0.5 in this study (e.g., attitude toward behavior with AVE=0.4248, Subjective norm with AVE=0.4003, perceived value with AVE=0.4017, intention toward behavior with AVE=0.4711), the possible reasons include: 1) The measurement items of these variables may have insufficient discrimination; for example, some items in 'attitude toward behavior' may overlap with the connotation of 'perceived value' (e.g., both involve evaluation of environmental benefits), leading to reduced variance explained. 2) The rural context-specificity of the variables; concepts like 'Subjective norm' in rural areas are more influenced by clan relationships and village regulations, while the current scale mostly references urban research frameworks, resulting in a mismatch between measurement dimensions and rural reality. Moreover, there is no need to reject

the model outright [72]. The AVE and CR values of attitude toward behavior, Subjective norm, and perceived value of intention toward behavior are lower than the standard measures, but the AVE values are all greater than 0.4, and the CR values are all greater than 0.6, which can be accepted to default to a better model aggregation validity in the context of a good overall model fit. A reliability test was conducted for the factors of the seven dimensions, and the KMO values of each dimension are all greater than 0.5, presenting significance at a significance level of 0.05, which is considered valid for analysis, indicating that the scale has good reliability and accuracy. The reliability coefficient is higher than 0.80, indicating that the questionnaire has credibility in all dimensions, and the data are real and reliable.

4.2. Divergent validity

In this study, the AVE method was used to assess discriminant validity, where the average variance extracted AVE of each factor with an open root sign is greater than the correlation coefficient, indicating that there is discriminant validity between the factors. The correlations between the dimensions were analyzed using the AMOS software. As shown in Table 4, all values on the diagonal are higher than those on the off-diagonal, indicating that the scale has discriminant validity. In summary, all the scales of the questionnaire in this study have good structural validity.

Table 4. Divergent validity.

	Attitude	Subjective norm	Perceptual-behavioral control	Perceived value	Perceived risk	Past experience	Attitude toward behavior
Attitude toward behavior	0.652						
Subjective norm	0.907	0.633					
Perceptual-behavioral control	0.546	0.494	0.765				
Perceived value	0.807	0.825	0.542	0.634			
Perceived risk	0.413	0.406	0.294	0.465	0.804		
Past experience	0.326	0.283	0.626	0.281	0.250	0.750	
Intention toward behavior	0.685	0.682	0.589	0.763	0.477	0.481	0.686

*Note: Bolded numbers on the diagonal are the square root of the mean variance extracted for the corresponding dimension, and off-diagonal numbers are the inter-dimensional correlation coefficients.

4.3. Major effects results

To explore the mechanisms influencing farmers' participation willingness in rural household waste source separation and reduction, we used structural equation modeling to test the proposed hypotheses. The structural model explains the relationship between latent variables through a variable covariance matrix. Below, we first present statistical results (model fit indices, path coefficients) and then provide interpretive discussions, with unified use of "participation willingness" (consistent with Figure 2) to avoid confusion between "behavioral intention" and "participation willingness". In this paper, AMOS24. 0 software was used to draw the structural equation modeling diagram, as shown in Figure 3.

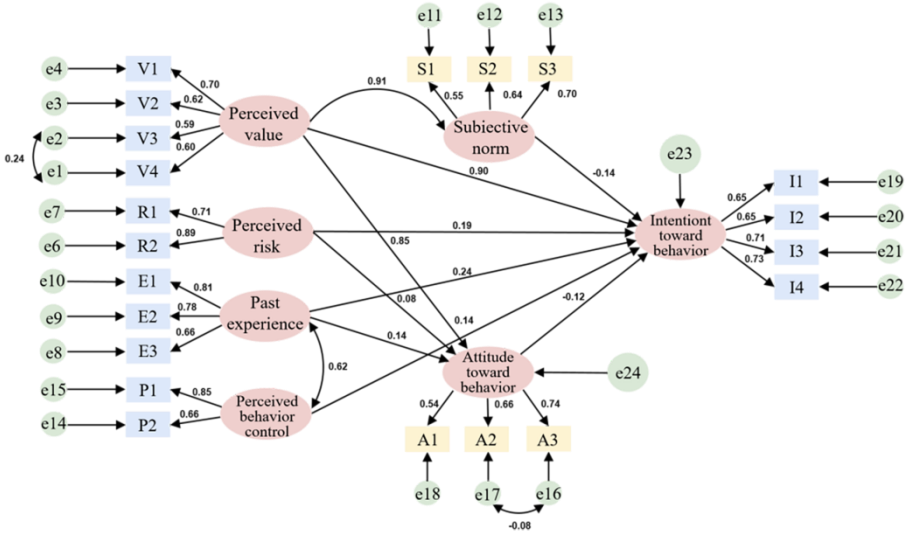

Figure 3. Structural equation mode.

To examine the fit of the model, we selected specific rating indicators and the categories to which they belonged, as shown in Table 5, and examined the fitting effect of the model by comparing the evaluation criteria of the individual indicators with the actual fitted value of the model.

Table 5. Major indicators of the model fitness test.

Fitness index	CMIN/DF	RMSEA	GFI	AGFI	CFI	IFI	TLI
Fitted parameter	2.930	0.066	0.901	0.869	0.899	0.900	0.879

According to the results of the model fitness test in Table 5, it can be seen that CMIN/DF = 2.930, which is in the range of 1–3, and RMSEA = 0.066, which is well within the range of 0.08, of which the test results of IFL, TLI, and CFI have reached the excellent level of 0.9 or more. Such an adjustment takes into account the various problems that may be encountered in actual research, making the model evaluation more reasonable and close to the actual situation. Therefore, from the analysis results, it can be stated that the hypothetical model and survey data of this study fit well, and the CFA model of the influence mechanism of farmers' willingness to participate in source separation and reduction of rural household waste has a good fit.

The path analysis in Table 6 shows that attitude toward behavior do not have a significant positive predictive effect on the willingness of farmers to participate in source separation and reduction of rural household waste, which is not a denial of the value of attitudes per se, but highlights the complexity of rural environmental governance; the need to shift from "personal cognition" to "systemic support" and integrate policy, facilities, culture and other multidimensional interventions. Rather, it highlights the complexity of rural environmental governance, which needs to shift from "individual cognition" to "systemic support", integrating multidimensional interventions such as policies, facilities, and culture. Subjective norm does not have a significant positive predictive effect on farmers' willingness to participate in source separation and reduction of rural household waste, suggesting that there is no clear consensus on waste separation in rural household waste management, that policy directives are ambiguous, and that it is difficult for farmers to clearly perceive social pressure.

Table 6. SEM path relationship test results.

Hypothesize	Trails	Standardized path factorβ	S.E.	C.R.	Test results
H1	Attitude toward behavior→ Intention toward behavior	-0.134	0.197	-0.681	No
H2	Subjective norm→ Attitude toward behavior	-0.181	0.36	-0.504	No
H3	Perceived behavior control Intention toward behavior	0.134*	0.067	2.007	Yes
H4	Perceived Value→ Intention toward behavior	0.78*	0.317	2.464	Yes
H5	Perceived Value→ Attitude toward behavior	0.963***	0.094	10.267	Yes
H7	Perceived Risk→ Intention toward behavior	0.163***	0.046	3.586	Yes
H8	Perceived Risk→ Attitude toward behavior	0.063	0.037	1.679	No
H10	Past Experiences→ Intention toward behavior	0.201**	0.065	3.072	Yes
H11	Past Experiences→ Attitude toward behavior	0.109**	0.038	2.890	Yes

Note: * indicates significant at a significance level of 0.05. ** denotes significant at a significance level of 0.01. *** denotes significant at a significance level of 0.001.

Perceived behavior control, perceived value, perceived risk, and past experience have a significant positive predictive effect on farmers' willingness to participate in source separation and the reduction of rural household waste, with path coefficients of 0.134, 0.78, 0.163, and 0.201, respectively, indicating that perceived behavior control, perceived value, perceived risk, and past experience play a driving role in farmers' willingness to participate in source separation and the reduction of rural household waste. Perceived value and past experience have a significant positive predictive effect on

the attitude of farmers toward participating in rural domestic waste source separation and reduction behavior, with path coefficients of 0.963 and 0.109, respectively, indicating that perceived value and past experience play a driving role in the attitude of farmers toward participating in rural domestic waste source separation and reduction behavior. Among them, perceived risk does not have a significant positive predictive effect on farmers' attitudes toward participating in source separation and reduction of rural household waste, and farmers may not have a clear understanding of the specific risks of source separation and reduction, resulting in the perceived risk not forming substantial psychological pressure.

4.4. Mediating effects results

The bootstrap method embedded in AMOS 24.0 was employed to examine the mediating effect. For this analysis, 5000 bootstrap resamples were conducted, with the error correction interval set at 95%. Initially, the coefficients of variables within the model were tested, followed by an assessment of the mediating role of attitude toward behavior [73], and the results are shown in Table 7. The final results were judged to include 0 under the 95% confidence interval to test whether a mediating effect existed [74].

Table 7. Perceived value PROCESS Distributional regression method mediation effect test results.

Implicit variable	Independent variable	R	R-sq	F	β	T-value
Attitude toward behavior	Perceived value	0.5697	0.3245	211.4004***	0.5697***	14.5396
Intention toward behavior	Perceived value	0.5851	0.3423	229.042***	0.5851***	15.1341
Intention toward behavior	Perceived value	0.6246	0.3901	140.4206***	0.4336***	9.5602
	Attitude toward behavior				0.266***	5.8659

In carrying out the mediating effect, the variables of the model were tested first, and it can be found that there is a significant positive relationship between perceived value and attitude toward behavior, a significant positive relationship between perceived value and behavioral willingness, and a significant positive relationship between perceived value and attitude toward behavior on behavioral willingness. Therefore, the coefficients in (2) and (3) in Eqs (2) and (3) are significant; therefore, the mediating role of attitude toward behavior can be tested.

As shown in Table 8, perceived risk has a significant positive effect on both behavioral attitude and behavioral intention. Specifically, the regression coefficient of perceived risk on attitude toward behavior is 0.3005 with a t-value of 6.6081, and the regression coefficient on intention toward behavior is 0.3678, with a t-value of 8.2955. In addition, perceived risk and attitude toward behavior together have a significant effect on intention toward behavior, with regression coefficients of 0.2348 and 0.4424 and t-values of 5.6629 and 10.6703, respectively. This indicates that attitude toward behavior partially mediate the relationship between perceived risk and behavioral intention.

Table 8. Perceived risk PROCESS Distributional regression method mediation effect test results.

Implicit variable	Independent variable	R	R-sq	F	β	T-value
Attitude toward behavior	Perceived risk	0.3005	0.0903	43.6674***	0.3005***	6.6081
Intention toward behavior	Perceived risk	0.3678	0.1352	68.8161***	0.3678***	8.2955
Intention toward behavior	Perceived risk	0.5598	0.3133	100.161***	0.2348***	5.6629
	Attitude toward behavior				0.4424***	10.6703

Table 9 shows that past experiences have a significant positive effect on both attitudes toward behavior and intention toward behavior. The regression coefficient of past experiences on attitude toward behavior was 0.2438, with a t-value of 5.273. The regression coefficient of past experiences on behavioral willingness was 0.376, with a t-value of 8.5109. Moreover, past experiences and attitude toward behavior have a significant effect on behavioral willingness, with regression coefficients of 0.2668 and 0.448 and t-values of 6.6228 and 11.1217, respectively, suggesting that behavioral attitude plays a partial mediating role between past experience and behavioral intention.

Table 9. Results of the mediation effect test of the environmental regulation PROCESS distributional regression method.

Implicit variable	Independent variable	R	R-sq	F	β	T-value
Attitude toward behavior	Past experience	0.2438	0.0594	27.8046***	0.2438***	5.273
Intention toward behavior	Past experience	0.376	0.1414	72.4359***	0.376***	8.5109
Intention toward behavior	Past experience	0.5745	0.3301	108.1639***	0.2668***	6.6228
	Attitude toward behavior				0.448***	11.1217

From the results of the mediation effect test using the bootstrapping method in Table 10, it can be found that attitude plays a mediating role between perceived value and behavioral attitude. We used the bootstrap technique to test attitude toward behavior, and it can be seen that the value of the indirect effect is 0.1329, and the 95% confidence interval [0.094, 0.212] does not contain 0, meaning that the indirect effect is established; thus, attitude toward behavior between perceived value and attitude toward behavior play a significant mediating role, and the confidence interval of the direct effect is [0.344, 0.523], which does not contain 0. This indicates that the direct effect is established.

According to the results of effect share calculations, it can be seen that the effect share of behavioral attitude is 25.98%, and hypothesis 6 is established.

Table 10. Bootstrap mediation effect test results.

Items	Trails	Efficiency value	Confidence interval (math.)	Efficiency ratio	Test results
Aggregate effect	Perceived Value→ Intention toward behavior	0.585	[0.509, 0.661]		Statistically significant
Direct effect	Perceived Value→ Attitude toward behavior	0.434	[0.344, 0.523]	74.19%	Statistically significant
Indirect effect	Perceived value→ Attitude toward behavior→ Intention toward behavior	0.152	[0.094, 0.212]	25.98%	Statistically significant
Aggregate effect	Perceived risk → Attitude toward behavior	0.368	[0.281, 0.455]		Statistically significant
Direct effect	Perceived risk → Attitude toward behavior	0.235	[0.153, 0.316]	63.86%	Statistically significant
Indirect effect	Perceived Risk → Behavioral Attitude → Behavioral Intention	0.133	[0.081, 0.189]	36.14%	Statistically significant
Aggregate effect	Past experience → Attitude toward behavior	0.376	[0.289, 0.463]		Statistically significant
Direct effect	Past experiences → Attitude toward behavior	0.267	[0.188, 0.346]	70.96%	Statistically significant
Indirect effect	Past experiences → Attitude toward behavior → Intention toward behavior	0.109	[0.064, 0.157]	29.04%	Statistically significant

The mediating role of attitude toward behavior between perceived risk and attitude toward behavior was tested, and it was found that the value of the indirect effect is 0.152, and the 95% confidence interval [0.081, 0.189] does not contain 0. This means that the indirect effect is established, so that attitudes toward behavior play a significant mediating role between perceived risk and Attitude toward behavior, and the confidence interval of the direct effect is [0.153, 0.316] and does not contain 0, indicating that the direct effect holds. According to the results of effect share calculation, it can be seen that the effect share of behavioral attitude is 36.14%, and Hypothesis 9 is established.

The mediating role of attitude toward behavior between past experiences and intention toward behavior was tested, and it can be seen that the value of the indirect effect is 0.109, and the 95% confidence interval [0.064, 0.157] does not contain 0, indicating that the indirect effect is established. Thus, attitudes toward behavior play a significant mediating role between past experiences and intention toward behavior, and the confidence interval of the direct effect [0.188, 0.346] does not contain 0, indicating that the direct effect holds. According to the results of effect share calculation, it can be seen that the effect share of behavioral attitude is 29.04%, and hypothesis 12 is established.

4.5. Results of moderating effects

To test the moderating effect, attitude toward behavior was designated the independent variable, environmental regulation as the moderating variable, and behavioral intention as the dependent variable, with SPSS 27.0 software employed for data analysis. As shown in Table 11, environmental regulation positively predicted households' willingness to use clean energy, with a moderating effect value of 0.3626 and P<0.001. The moderating effect value of the interaction term between attitude toward behavior and environmental regulation is -0.0965, P < 0.05, with 95% confidence intervals [-0.1702, -0.0228], which does not contain 0. Validating H13, environmental regulation plays a moderating role in attitude toward behavior.

Table 11. Test results of the moderating effect of environmental regulation.

Items	Effect	SE	LLCI	ULCI
Attitude toward behavior	0.3671***	0.0408	0.287	0.4472
Environmental regulation	0.3626***	0.0394	0.2851	0.4401
Attitude toward behavior* Environmental regulation	-0.0965*	0.0375	-0.1702	-0.0228

The results of the simple slope test for environmental regulation, attitude toward behavior, and behavioral willingness are shown in Table 12. According to the results of Figure 4, the slopes of the straight line of low environmental regulation and high environmental regulation show an increasing trend, indicating that with the continuous improvement of attitude toward behavior, farmers' awareness of source separation and reduction of rural domestic garbage is continuously increasing. Among the slopes of the two straight lines, the slope of low environmental regulation is larger than that of high environmental regulation, indicating that the positive influence of farmers' attitude toward rural household waste source separation on behavioral intention decreases as environmental regulation intensity increases. This confirms environmental regulation's inverse moderating role in the relationship between behavioral attitude and behavioral willingness: Under high environmental regulation intensity, the promoting effect of positive behavioral attitude on participation intention is significantly weaker than under low intensity. This further supports the existence of the 'psychological resistance' effect; rigid or overly intensive regulatory measures may make farmers feel their participation is driven by external pressure than internal recognition, thus weakening the predictive role of attitude on intention. The influence of farmers' attitude toward behavior toward source separation and the reduction of rural domestic garbage on behavioral willingness is weaker, which indicates that farmers may perceive their own behavior as being restricted and produce psychological resistance. The original positive attitude could not be transformed into willingness because of resistance.

Table 12. Simple slope test results.

Moderating variable: environmental regulation	Effect	S. E.	LLCI	ULCI
Low level (M=-1SD)	0.464***	0.048	0.370	0.558
Average (M)	0.367***	0.041	0.287	0.447
High level (M=1SD)	0.271***	0.062	0.149	0.392

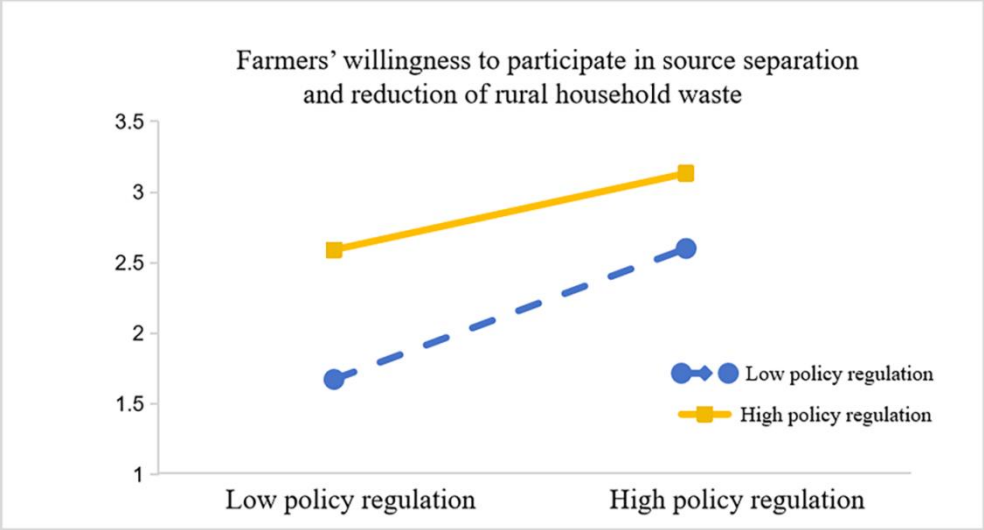

Figure 4. The moderating role of environmental regulation in attitude toward behavior and intention toward behavior.

4.6. Discussion

By synthesizing the outcomes of the research hypotheses and their respective tests, the results of hypothesis verification for the model examining farmers' willingness to participate in rural household waste source separation and reduction are presented in Table 13.

(1) Theoretical deepening of major effects and contextual differences. This study revealed the specificity of rural garbage sorting behavior: The direct effects of attitude toward behavior and Subjective norm on willingness to participate does not pass the significance test, which is significantly different from the findings of the traditional TPB in urban studies [75]. This difference mainly stems from the systemic shortcomings of rural governance; ambiguity in policy implementation leading to weak binding social norms, weak infrastructure limiting behavioral feasibility, intergenerational digital divide exacerbating barriers to participation for older groups, lack of social consensus, and weak infrastructure [76], which makes it difficult for farmers to rely solely on psychological recognition or social pressure to form the willingness to participate. For example, the finding that farmers are more concerned with the practical feasibility of categorizing behaviors than with abstract social norms challenges the analytical framework of the literature that relies excessively on psychological variables and emphasizes the need to shift from "individual perceptions" to a multidimensional policy-facility-culture intervention.

(2) Mechanistic innovations in mediating effects and city comparisons. In this study, we integrate past experiences and expand the explanatory boundary of the TPB model and "past experience" and "perceived risk". The mediating effect of attitude toward behavior shows that perceived value and past experiences indirectly drive farmers' willingness to participate in waste sorting through attitude reinforcement [77], whereas perceived risk directly promotes farmers' willingness to participate but does not significantly affect their attitudes [78]. This finding reveals the "instrumental" nature of risk perception in the rural context, where farmers' participation in the source separation of waste is more about avoiding threats to their surroundings than forming a tangible internal identity. In contrast to urban studies that emphasize risk-attitude mediation, this study suggests that rural environmental

governance needs to strike a balance between risk warning and value incentives and that economic-ecological dual-objective incentive policies can be designed. For example, linking sorting behavior to "green points", which can be exchanged for discounts on agricultural supplies or health insurance subsidies, can enhance the benefits generated by farmers' participation in waste sorting.

Table 13. Results of hypothesis testing.

Hypothesize	Hypothetical content	Test results
H1	Attitude toward behavior have a positive effect on the willingness of farmers to participate in source separation and reduction of rural household waste participation.	Fail
H2	Subjective norm has a positive effect on the willingness of farmers to participate in source separation and reduction of rural household waste.	Fail
H3	Perceived behavior control Positively Influences farmers' Willingness to Participate in Source Separation and Reduction of Rural Domestic Waste Participation	Pass
H4	Perceived value positively affects farmers' willingness to participate in source separation and reduction of rural household waste participation.	Pass
H5	Perceived value positively influences farmers' attitudes toward participation in source separation and reduction of rural domestic waste.	Pass
H6	Attitude toward behavior mediate between perceived value and willingness to participate.	Pass
H7	Perceived risk positively affects farmers' willingness to participate in source separation and reduction of rural household waste participation.	Pass
H8	Perceived risk positively affects farmers' attitudes toward participation in source separation and reduction of rural household waste.	Fail
H9	Attitude toward behavior mediate between perceived risk and willingness to participate.	Pass
H10	Past experience positively influences farmers' willingness to participate in source separation and reduction of rural household waste.	Pass
H11	Past experience positively influences farmers' attitudes towards participation in source separation and reduction of rural household waste.	Pass
H12	Attitude toward behavior mediate between past experiences and willingness to participate.	Pass
H13	Environmental regulation has a significant moderating effect on the volitional relationship.	Pass

(3) Policy Implications of Regulatory Effects and Governance Transformation. The negative moderating effect of policy regulation was the core breakthrough of this study. High-intensity administrative interventions weaken the efficiency of attitude toward behavior on farmers' willingness to participate in rural waste sorting, confirming the hypothesis that if the government implements a rigid policy on waste sorting, it is likely to trigger psychological resistance among farmers. This finding reverses the traditional "command-and-control" governance paradigm and calls for a transition to "flexible governance". Through participatory budgeting, farmers can take the lead in formulating rules about waste classification, or introducing carbon trading to transform environmental behavior into economic benefits, which can bring tangible benefits to farmers through waste classification. This not only reduces farmers' resistance to rigid policies, but also stimulates the endogenous motivation of farmers to participate in waste classification. Compared with the generalized "rigid policy-strengthen regulation" proposal in the existing literature, the differentiated path proposed in this study is more operative and pragmatic, and provides an example of theory; practice two-way innovation for farmers to participate in the source separation and reduction of rural household waste.

A notable limitation of this study is the over-representation of highly educated groups in the sample. As shown in Table 1, 49.1% of respondents have a college degree or above, far exceeding China's rural population's national average college education rate (about 12%, per 2024 rural data from China's National Bureau of Statistics). This not only fails to reflect China's rural reality (low- and middle-education farmers are the majority) but may also overestimate farmers' participation willingness in waste source separation; highly educated farmers have stronger environmental awareness and value recognition of sorting, which easily boost their willingness.

This bias may affect the generalizability of conclusions; For example, the significant positive effect of perceived value (β=0.78, Table 5) and the mediating role of behavioral attitude (e.g., 25.98% effect ratio, Table 9) may be weaker in low-education groups, who care more about short-term material benefits than abstract values or attitudes.

Thus, policies based on this study's conclusions should be applied cautiously to low-education farmers. Future studies should expand samples of low- and middle-education farmers to improve conclusion generalizability.

5. Conclusions

Based on the TPB framework, we integrate the variables of perceived value, perceived risk, past experience, and policy regulation and construct a three-dimensional analysis model of psychology-behavior-environment to systematically explore the mechanisms influencing farmers' willingness to participate in source separation and reduction of rural household waste. The empirical findings reveal the following: (1) Among the core variables, perceived behavioral control, perceived value, perceived risk, and past experience exert a significantly positive impact on farmers' willingness to engage in waste classification. Notably, perceived value exhibits the highest path coefficient, suggesting that farmers' perceptions of economic benefits and environmental improvements serve as the core drivers of their participation. The direct influence of attitude toward behavior and Subjective norm did not pass the test, indicating that rural garbage classification has not formed a broad social consensus and that the ambiguity of policy directives makes it difficult for farmers to perceive social pressure. (2) Attitudes toward behavior play a mediating role between perceived value, perceived risk, past experiences, and willingness to participate, which verifies the psychological transmission path of

"value perception-attitude reinforcement-behavioral transformation". (3) Environmental regulation presents a "double-edged sword" effect, which negatively moderates the relationship between behavioral attitude and participation willingness, indicating that rigid environmental regulation may enhance garbage sorting efficiency in the short term but may trigger psychological resistance and inhibit farmers' endogenous motivation. (4) The analysis of group heterogeneity reveals that highly educated and high-income farmers are more actively involved because of the advantage of information acquisition, while the elderly group is negative because of the lack of knowledge and habitual curing of farmers. The study suggests that multi-dimensional synergy is needed to solve the dilemma of "government hot, farmers cold." Thus, cognitively driven value recognition should be strengthened through a stratified education. Cultural infiltration, relying on clan networks to build a "face constraints" mechanism, and realize the "policy adaptation-psychological drive-behavioral transformation-institutional safeguards" governance closed loop.

6. Future direction

6.1. Implications

6.1.1. Theoretical implications

We draw on and integrate the TPB, the theory of perceived value, the theory of risk perception, and the framework of policy regulation and construct a three-dimensional analysis model of "psychology-behavior-policy", which provides an important theoretical extension for the study of source reduction of rural garbage classification. At the level of variable integration, we break through the limitations of the traditional TPB model, and for the first time, incorporate "past experience" into the framework, revealing the mechanism by which past experience indirectly drives the willingness to participate in garbage sorting by strengthening the inherent attitudes of farmers. This makes up for the neglect of feedback from past experience in the literature. Moreover, the variable of "perceived value" is introduced to emphasize the central role of farmers' assessment of actual value, such as economic gain and environmental improvement, in decision-making. This deepens the understanding of the interaction between the economic rationality and psychological cognition of rural residents. Second, at the level of mechanism innovation, we verify the mediating effect of attitude toward behavior and found that perceived value, perceived risk, and past experiences indirectly affect farmers' willingness to participate in waste sorting through attitudinal transformation, which reveals the function of psychological cognition in bridging the gap between external stimuli and attitude toward behavior. This finding suggests that external incentives and internal identity are necessary to drive rural environmental governance. In addition, the study reveals, for the first time, the negative moderating effect of environmental regulation, suggesting that high-intensity administrative interventions may inhibit the formation of endogenous motivation of farmers, which provides a new perspective for public policy theories and suggests that policy design needs to balance the "rigid constraints" and "flexible guidance". Compared with urban studies that emphasize the direct role of social norms and attitudes, this study reveals the specificity of the rural context: Weak infrastructure, elasticity of policy implementation, and lack of social consensus have led farmers to rely more on practical feasibility than abstract norms. This suggests that future theory building should focus on urban-rural differences, strengthen interdisciplinary integration, and explore nonlinear interaction effects. Overall, this study

provides a more explanatory analytical framework for the dilemma of rural garbage sorting by integrating multidimensional theories with a specific rural context and opens a new path for behavioral theory research.

6.1.2. Practical implications

This study provides important practical insights for the study of source reduction in rural garbage classification. Rural household waste management needs to shift from single to "multi-dimensional", and build a management model with multiple policy mechanisms in parallel. First, it deepens farmers' knowledge. We should design a hierarchical education system to address group heterogeneity: For the elderly, launch a 'neighborhood pairing' assistance program; matching 2 elderly farmers with 1 young/middle-aged farmer (preferably with higher education) who provides weekly home visits to demonstrate sorting operations (e.g., marking 'kitchen waste' and 'recyclables' bins with colored stickers) and distribute picture-based sorting manuals (to avoid excessive text). Set up an 'elderly sorting reward station' in the village committee, selecting 'excellent sorting elders' monthly and rewarding them with daily necessities (e.g., rice and flour), aligning with the study's finding that 'perceived value is a core driver' by providing tangible benefits, while using field demonstrations to lower the operation threshold; for the young and middle-aged, push classification knowledge via digital platforms and introduce new technologies to strengthen rural garbage risk perception through environmental risk visualization. Second, we optimize the behavioral incentive mechanism. Moreover, institutional innovation should be promoted, and a flexible system of incentives should be implemented. Third, promote institutional innovation and implement a flexible governance model with group-specific reward mechanisms: For elderly farmers, set up 'tangible reward stations' in villages, redeeming correct sorting records for daily necessities (e.g., 10 records for a bag of rice) to align with their preference for visible benefits; for young and middle-aged farmers, integrate the 'classification-recycling-revenue' closed loop with digital platforms, enabling them to sell sorted recyclables via the village-level recycling station and receive payments directly through mobile wallets, while linking high sorting performance to preferential policies (e.g., priority access to rural e-commerce subsidies). Reduce rigid policy coercion and pilot 'participatory budget management' where farmers jointly formulate group-adapted classification rules and reward standards to enhance policy identity and practical benefits for different groups. Fourth, technical empowerment by developing low-cost intelligent equipment tailored to the information-acquisition habits of farmers with higher education and income. Record each correct waste-sorting behavior of this group via block chain technology, automatically accumulating 10–20 'green points' that can be exchanged for agricultural technology services (e.g., free soil testing and priority access to high-quality seedlings). Moreover, select this group as 'village-level waste-sorting technical consultants', offering a monthly labor subsidy of 200–300 yuan to guide other farmers in using intelligent sorting equipment, leveraging their past sorting experience (consistent with the positive impact of 'past experience' on participation willingness verified in this study) to form a demonstration effect, enhancing the operability of waste classification for all farmers. In addition, efforts should be made to improve infrastructure, configure garbage classification facilities according to the needs of different regions, and establish a regional collaboration mechanism in the East, Central, and West to share governance experiences. Specifically, in response to the insignificant direct effects of attitude and Subjective norm on participation willingness (H1 and H2 in Table 5), infrastructure improvement should be paired with normative

guidance: For instance, while installing classified bins, post village-level sorting rules and model household lists nearby to simultaneously address structural barriers and normative ambiguity, bridging the gap between individual attitudes, social norms, and participation behavior.

6.2. Research gaps and future directions

This study has two key limitations. First, sample representativeness is constrained: The sample exhibits a bias toward younger (18–30 years old accounting for 44.3%) and higher-educated (college degree or above accounting for 49.1%) groups, which deviates from the demographic structure of China's overall rural population (with higher proportions of middle-aged and elderly, and lower college education rates). This bias may overestimate the positive impact of factors like digital literacy and perceived value on participation willingness, reducing the generalizability of conclusions to elderly and low-education farmer groups. Second, dynamic evolution of behavior is insufficiently considered: Cross-sectional data fails to capture the long-term evolution of farmers' waste-sorting willingness and behavior, making it difficult to identify the time-lag effect of policy impacts and attitude changes. In terms of future research directions, first, expand the sample coverage of low-education farming households (e.g., increasing the proportion of respondents with junior high school education or below to match the national rural education structure) to address the current over-representation of highly educated groups (49.1% with college degree or above, as shown in Table 1). This will help reduce the overestimation of participation willingness and improve the alignment of research conclusions with China's rural reality. Second, the sample coverage of low-income farming households should be expanded in questionnaire research to make the research results more convincing.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Conflicts of interest

The authors declare no conflict of interest.

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