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Public acceptance of residential photovoltaic installation: A case study in China

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ABSTRACT

Residential photovoltaics (PV) presents an effective means of achieving low-carbon development, owing to its installation flexibility and resource-saving properties. To explore the residents' behavioral intentions to purchase and install residential PV systems, this study collected 1424 samples and analyze the impact of different policies on residents' adoption of residential PV using the theory of TPB and the Partial Least Squares Structural Equation Model (PLS-SEM). The main conclusions are summarized as follows: (1) Bungalow residents exhibit a stronger inclination to install residential PV than building residents. (2) Perceived reward (PR) affects installation intention (II) more than perceived guide (PG) among bungalow residents. (3) Both PR and PG indirectly affect II through Perceived behavioral control (PBC) among bungalow residents. Economic policies, represented by PR, are likely to have more substantial indirect effects than propaganda and guidance policies. The findings suggest that China's recent residential PV installation policies should increase users' trust and guide the future decline of subsidy policy.

1. Introduction

China, as the world's largest power generator, faces challenges owing to its coal-based electricity mix, contributing significantly to greenhouse gas emissions [1]. In 2022, China's carbon emissions were 110.4 billion tons, accounting for 28.9 % of the world's emissions [2]. China's heavy reliance on fossil fuels and widespread development have resulted in serious environmental and social problems. For instance, haze spread across half of China between 2012 and 2018 [3] and power rationing occurred in 2021 during the summer and autumn [4]. Until 2022, the proportion of coal in China's overall energy consumption structure will be as high as 56.2 % and the use of clean energy in China's energy consumption structure will be relatively low [5]. From the proportion of installed power capacity, China's total installed power capacity will be 256235.3 GW by the end of 2022, of which coal accounts for 43.8 %, hydropower accounts for 16.1 %, solar energy accounts for 15.3 %, wind energy accounts for 14.3 %, nuclear power accounts for 2.2 % and biomass energy accounts for 1.6 %, the entire power generation system in China still relies mainly on coal-fired power [6]. To address these concerns and pursue sustainable development goals, the "double carbon target" was proposed during the 75th United Nations General Assembly in September 2020, aiming for carbon neutrality by 2060 [7]. Thus, China developed the "Outline of the Fourteenth Five-Year Plan (2021–2025) for National Economic and Social Development" and "Vision 2035 of the People's Republic of

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List of abbreviations

TPB	Theory of Planned Behavior
PA	Personal Attitudes
SN	Subjective Norm
PBC	Perceived Behavioral Control
PR	Perceived Reward
PG	Perceived Guide
GI	Government Incentives

China." These plans emphasize reducing energy consumption intensity and carbon dioxide emission intensity by 13.5 % and 18 %, respectively. Clean energy adoption, particularly solar energy, is crucial in achieving the "dual carbon goal" [8,9] rather than relying on highly polluting and non-renewable sources [10,11].

Solar energy emerged as the most promising renewable energy of the 21st century, given its wide distribution and potential [12,13]. Most countries have accelerated solar energy development and utilization owing to its "inexhaustible" nature [14]. Developing solar energy offers an appropriate pathway towards sustainable development by replacing fossil fuels and reducing greenhouse gas (GHG) emissions [15]. Unlike conventional fossil fuels, centralized photovoltaic (PV) power plants have limitations such as extensive land requirements, fluctuating power output, and operational challenges, leading to erratic power supply [16]. In response, the Chinese government has actively promoted decentralized PV systems on roof and walls to mitigate these difficulties and significantly reduce land use costs [17,18]. Such systems, known as residential PV systems, have gained momentum [19]. The Chinese government issued "Interim Measures for the Management of Financial Subsidies for the Golden Sun Project" to initiate central government subsidies for residential PV systems [20]. As a result of government-imposed, the clean heating project in northern China has achieved significant results since 2017. This includes a clean heating rate exceeding 60 % and replacing approximately 140 million tons of unburned coal. Rural electricity consumption has been transformed and upgraded in China through a new round of rural power grid transformations, with a rural electrification rate of 18.0 % and a comprehensive voltage qualification rate of 99.7 % [21]. In order to alleviate poverty, we have implemented PV poverty alleviation projects tailored to local conditions, which can generate approximately 2.5 billion USD in annual electricity generation revenue and benefit over 4 million impoverished households. Zhang et al. [22] considered 35.0 % rooftop area availability, rooftop PV would reduce carbon emissions by nearly 4 billion tons in 354 cities in China by 2020, which is approximately 70.0 % of the total carbon emissions generated by the electric and heat industry. As a result, China's cumulative installed capacity of residential PV increased from 0.9 GW in 2016 to 20.0 GW in 2020 [23], with an average growth rate exceeding 40.0 % [24]. Residential PV systems convert solar energy into electrical energy without producing greenhouse gas emissions. The surplus electricity can be sold to the power grid, generating profits and qualifying for government subsidies [25,26]. Thus, residents can benefit economically while contributing to environmental protection and sustainable development at the macro level. Residential PV systems and their use have become focal points of academic and practical research [27].

China's PV promotion policy has changed since 2020, with the central government gradually withdrawing subsidies for residential PV installation and usage, referred to as the "subsidy recession" [28,29]. To set an example for residents, the Chinese government mandated local governments, government entities, and public institutions to install residential PV panels [28,29]. Such policy changes are likely to affect the popularity of PV systems among residents. Currently, limited literature explores the impact of changes in Chinese PV subsidy policies on residents' willingness to install PV systems and whether the timing of the subsidy reduction is appropriate. Considering changes in PV promotion policies and declining residential PV subsidies, this study aims to examines the role and impact of policy changes on Chinese residents' inclination to install PV systems and address the following two questions: 1) Do changes in China's PV subsidy policies affect residents' willingness to install PV systems? 2) Will changes in residents' living conditions resulting from urbanization influence their inclination to install PV systems on residential buildings?

2. Literature review

PV technology has garnered significant attention owing to its huge growth potential [12]. Jaffe and Stavins [30] observed that after 30 years of promotion, the penetration rate of economically efficient renewable PV technology remains merely 20 %–25 % of its market potential, leading to what they termed the Jaffe-Stavins paradox. Neves et al. [31] propose that stimulating residents' willingness to adopt renewable energy technologies is crucial to resolving this paradox. To address this issue, social psychologists often employ the Theory of Planned Behavior (TPB) to explore public adoption of environmental protection products [32]. The TPB has earned its status as a classic theory for several reasons: First, its versatility allows for explaining and predicting various behaviors. Second, this theory is grounded in research on individual intentions and decision-making, providing high interpretability. Furthermore, empirical research has widely validated its effectiveness. Last, the TPB provides valuable guidance in formulating intervention strategies and driving behavioral change, making it highly relevant in practical applications [33].

Numerous studies have confirmed the theoretical effect of the TPB model in explaining public willingness to adopt environmental protection measures [34], with two research directions based thereon having been developed to explain residents' inclinations to adopt ecofriendly products. Direction 1: Integrate the TPB model with other motivation theories to explain why residents are willing to adopt environmentally friendly products. Depending on the motivation of the residents, this type of research can be divided into studies integrating both utilitarian and altruistic motivation. Utilitarian motivation entails the combination of the TPB model with the Technology Acceptance Model (TAM) to elucidate residents' adoption of environmentally friendly products [35], whereas altruistic motivation involves employing the TPB model in conjunction with the Value Belief Norm Theory (VBN) to explain residents' acceptance of environmentally friendly products [36]. A number of research results were also obtained by combining demographic characteristics [37], resident values [38], and resident personality traits [39,40]. Direction 2: Develop a structural equation model to explain residents' adoption behavior of environmentally friendly products based on the TPB model and external scenarios. Research into this behavior is still in its infancy, and there is only limited literature available on this topic. For instance, Hsu et al. [41] combined the price of environmentally friendly skincare products with TPB to study young consumers' willingness to consume green cosmetics, while Liobikien ė et al. [42] combined social and cultural factors with TPB to explore consumers' green purchasing behavior. Direction 1 contributes a significant portion of empirical evidence to research regarding the promotion of environmentally friendly products. Direction 2 provides new theoretical growth points for this field. Although Direction 2 still has gaps that need to be gradually filled, the TPB model has continuously developed over the previous decades, forming a systematic and comprehensive theoretical framework. However, few studies have combined TPB model with the external environment of human life to explain human environmental protection behavior. This study focuses on residential PV adoption behavior, and the external variables that affect residents' adoption, including government policies [24] and residential conditions [40] to analyze the factors that affect residents' installation of residential PV and the role of government policies. Filling the gaps in this field promotes the development of Direction 2.

3. Empirical strategy

3.1. Theoretical foundation

Most Chinese families consider the elevated economic cost and the change in the aesthetic of the house when installing residential PV system. For example, a residential PV system of 5 kW can be installed on a 100 square meter roof. The current cost of a PV system is approximately 0.9751–1.1144 USD per watt (CNY to USD exchange rate on November 30, 2022 is 1 CNY = 0.1393 USD, the same goes for the following text), which means that installing such a system would cost between 4875.5 and 5572.0 USD on a 100 square meter roof [43].

Whether such a system is used depends on how many economic and psychological benefits residents might reap from the installation and other post-installation advantages [24]. It is highly recognized in the field of social psychology [40] and widely used in the field of pro-environmental behavior [44], which is suitable for determining the factors considered in residential PV adoption. The TPB model assumes that people in the decision-making process use a rational-dominated process, and most studies discussed the TPB model's effect on the individual's belief of environmental behavior mainly by considering three variables [45]: (1) Personal attitudes (PA), (2) subjective norms (SN), and (3) perceived behavioral control (PBC).

Residential PV installations may affect PA owing to their expectations of behavioral consequences. These may include the benefits and the cost generated by installing residential PV generations, the risk of using such equipment, and whether such equipment in the real sense, can reduce environmental pollution, etc. [33]. People experience SNs when planning an action [46]. Specifically, in terms of whether to use residential PV systems, the user experience of the neighbors and whether to support the use will impact the purchase decision of the household appliances. If a large number of people are encouraged to install the residential PV systems, residents nearby will be more inclined to use them, and vice versa [47]. When people decide whether to act, PBC depends on whether they feel capable of carrying out the action [45]. Regarding residential PV generations, the maintenance costs and the amount of people's solar product knowledge may significantly impact PBC [48]. Within the TPB model, the willingness of residents to install PV systems can be explained internally. Furthermore, social psychology posits that alterations in individual perceptions of the external environment affect internal psychological perceptions, and ultimately behavior. The model of attitude, behavior, and context was developed to understand how an individual's perception of politics affects their behavior [49,50]. Muhammad-Sukki [51] reported that government policy is essential in implementing residential PV power generation. Additionally, government policies can assist residents become more motivated to use smart grid services [52–54]. However, few studies combine internal and external driving factors with studying residents' willingness to install residential PV.

This paper extends the TPB model and focuses on analyzing the effects of electricity price subsidies and steering measures on PA, SN, and PBC, respectively. Simultaneously, this study discusses the mediating role of PA, SN, and PBC between the PR and PG, revealing attitudes and intentions towards installing a residential PV system.

3.2. Hypotheses

3.2.1. Personal Attitudes (PA)

PA refers to a person's favorable or unfavorable evaluation of a particular behavior or interest [45]. Abreu et al. [49] reported that a positive attitude statistically influences the installation intention (II) of residential PV systems. In this study, attitude represents consumers' valuation of residential PV systems. Thus, we hypothesize that.

Hypothesis 1. (H1). PA is positively correlated with II.

3.2.2. Subjective norm (SN)

SN refers to the belief about whether most people approve or disapprove of a specific behavior and is influenced by personal feelings towards opinions of peers and those people they care about [45]. Korcaj et al. [55] state that positive feedback from peers regarding residential PV increases the likelihood of purchase and installation. Hence, the hypothesis below has been proposed.

Hypothesis 2. **(H2).** SN is positively correlated with II.

3.2.3. *Perceived behavioral control (PBC)*

PBC refers to individuals' perceived ability to achieve their current goals according to their experiences. The belief is that the more information, technology, resources, and opportunities they possess, the easier it will be to achieve their goals, and vice versa [27]. It reflects an individual's decision-making on a particular behavior and is a significant factor in predicting II [56].

Hypothesis 3. **(H3).** PBC is positively correlated with II.

3.2.4. *Perceived guide (PG)*

The Chinese government guides residents to install PV systems through various measures such as advertisements and demonstrations. This study defines the effect of government advertising and demonstration as "perceived guidance," which residents subjectively perceive. Publicizing energy conservation information and solar knowledge can improve residents' environmental awareness, thereby promoting energy-saving behaviors [57]. Wang et al. [58] report that the psychological distance between residents and residential PV products can be shortened through the guiding role of government advertising and demonstration, leading to increased II. In summary, the following assumptions are proposed.

Hypothesis 4. **(H4).** PG is positively correlated with II.

Hypothesis 5. **(H5).** PG is positively correlated with PA.

Hypothesis 6. **(H6).** PG is positively correlated with SN.

Hypothesis 7. **(H7).** PG is positively correlated with PBC.

3.2.5. *Perceived Reward (PR)*

Currently, local financial incentives in China include subsidies for grid-connected sale of residential PV systems according to their economic capacity. The essence of the subsidies is to promote the installation rate of residential PV systems, thereby encouraging adoption [59]. Previous studies have shown that government subsidy policies positively influence residents' intention to install residential PV systems [49]. PV systems on residential buildings can reduce electricity costs and provide additional community benefits to residents, thus positively affecting II [60]. The following assumptions can be put forward.

Hypothesis 8. **(H8).** PR is positively correlated with II.

Hypothesis 9. **(H9).** PR is positively correlated with PA.

Hypothesis 10. **(H10).** PR is positively correlated with ST.

Hypothesis 11. **(H11).** PR is positively correlated with PBC.

3.2.6. *Mediating effect hypothesis*

According to the aforementioned hypotheses from 3.2.1 to 3.2.5, the following hypotheses can be derived and tested together.

Hypothesis 12. **(H12).** PG can positively affect residents' II through PA (according to H1 and H5).

Hypothesis 13. **(H13).** PR can positively affect residents' II through PA (according to H1 and H9).

Hypothesis 14. **(H14).** PG can positively affect residents' II through SN (according to H2 and H6).

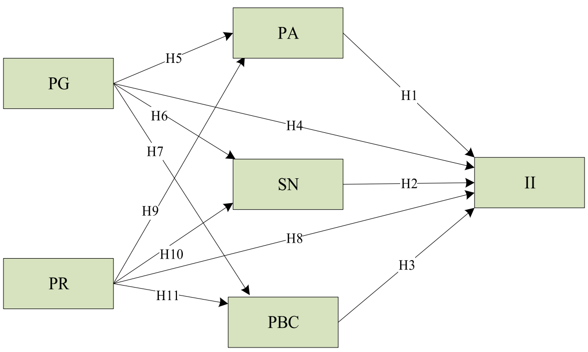

Fig. 1. Research Model. Notes: PG, Perceived Guide; PR, Perceived reward; PA, Personal Attitudes; SN, Subjective Norm; PBC, Perceived Behavioral Control; II, Installation Intention.

Hypothesis 15. **(H15)**. PR can positively affect residents' II through PA (according to H2 and H10).

Hypothesis 16. **(H16)**. PG can positively affect residents' II through PA (according to H3 and H7).

Hypothesis 17. **(H17)**. PR can positively affect residents' II through PA (according to H1 and H5).

Hypothesis 18. **(H18)**. PG has a significant mediating effect on residents' II (according to H12, H14, and H16).

Hypothesis 19. **(H19)**. PR has a significant mediating effect on residents' II (according to H13, H15, and H17).

As shown in Fig. 1, this study builds a research model based on TPB model to examine the relationship between consumer awareness of two policies and II. This study investigates the relationship between PR and PG and residents' willingness to install PV systems on residential buildings under different living conditions (bungalows and buildings). The intermediary variables are AT, SN, and PBC from the TPB model [45], the PR comes from the research of Stern [61] and Kim et al. [39], and the PG comes from the study of Wang et al. [58]. The integration of external and internal factors is intuitive and efficient, as shown in Fig. 1. Furthermore, this paper selects the PLS-SEM method to evaluate the model in Fig. 1. PLS-SEM has fewer requirements for sample data, making it more suitable for small samples and data that are not normally distributed. Moreover, it is more flexible than existing methods like Covariance-Based SEM (CB-SEM). PLS-SEM can handle both reflective and construct indicators simultaneously and is suitable for various types of variables (including continuous, binary, and ordinal). Additionally, PLS-SEM for exploratory research has strong prediction and interpretation capabilities and can deal with complex research problems, generating results suitable for management decision-making [62]. In this study, the analysis was conducted by combining the concept of policy perception with the TPB model, aiming to explore the pathways of different types of policies on residents' willingness to install residential PV systems.

3.3. Questionnaire design

In questionnaire design, content validity, convergent validity, and discriminative validity are three the main validity evaluation indicators [63]. Content validity monitors whether the selected items of the measurement tool fully meet the survey purpose and requirements [64]. The evaluation methods for content validity include expert judgment and empirical methods. The expert discrimination method is used in this study. The advantages of this technology include: rich professional knowledge, multi-angle evaluation and provide suggestions for improvement. Convergent validity reflects whether each scale indicator measures the same construct together. The higher the aggregated validity, the more accurately each item reflects the construct's connotation. Here we use (a) Cronbach's α and (b) Composite Reliability value to determine the construct [65]. This technology has the advantage of improving the quality and reliability of questionnaire surveys. Discriminant validity refers to the low correlation between the latent traits represented by two latent variables, even when measured using the same method, they still exhibit low correlation. This study aims to use Heterogeneous Elemental Ratio Analysis and Fornell Larcker Criterion to measure discriminant validity [65]. Its advantages include validating multiple related but independent concepts and evaluating the degree of differences. The measurement of discriminant validity will be elaborated in the questionnaire.

This study uses PLS-SEM to measure the variables in the questionnaire and the relationships between the variables, by using this method it could simultaneously consider the relationship between multiple latent variables, as well as the relationship between latent variables and observed variables. On the other hand, PLS-SEM can perform multi-group analysis, comparing data from multiple sample groups or different time points. In this study, a multi-group analysis function was used (comparison between the bungalow and the building group). Moreover, PLS-SEM is capable of analyzing causal relationships, provide path analysis, and structural modeling, which enable researchers to gain a deeper understanding of complex relationships and mechanisms between variable [66,67].

The questionnaire was reviewed by two experts from the Energy Research Institute of the National Development and Reform Commission of China. We incorporated the experts' feedback to finalize the questionnaire accordingly. The main variables are measured using a Likert 5-point scale, and the measurement scale and detailed questions are shown in Appendix S1**.** The PR was referenced from Stern [61] and Kim et al. [39], while the PG was referenced from Wang et al. [58]. Soliman et al. [68] used PA, SN, PBC, and II, referenced from Ajzen [45] and Wolske et al. [48]. Additionally, the questionnaire includes an option to indicate the living conditions (bungalow or building) to distinguish the samples in the survey.

3.4. Data

Statistical yearbook data of Hebei, Shandong and Henan provinces indicate that their population structure and energy structure ratios [79–81] are similar to those in the national statistical yearbook of 2021 [78], Hebei, Shandong, and Henan accounted for 84.6 % of the country's residential PV projects subsidized by national finance in 2021 (40.2 %, 32.3 %, and 12.1 %, respectively) [58,69], so data from these provinces would be more representative (Appendix S2 shows detailed population and energy structure). These provinces provided a typical sample for the analysis of purchase deciding factors and intention among different groups. These provinces provided a representative sample for the analysis of purchase deciding factors and intention among different groups. Owing to the government's regional isolation control during the COVID-19 pandemic, an online questionnaire survey was conducted. In October 2020, when China's regional isolation control was slightly loosed. Our team members did an on-site visit with families who both installed and not install residential PV system to heard their story about usage and reasons for not having it. In order to better understand the actual situation and evaluate the feasibility of the questionnaire questions, we establish contact with the respondents. We use snowball rolling sampling to ask them to pass along our questionnaire survey to their friends and relatives in their province. To prevent respondents from answering questions for extra red envelopes, we screen for duplicate *IP* addresses and delete duplicate samples. We also remove respondents who answered the survey carelessly or randomly. This survey was conducted in February 2022 and lasted for 30 days, resulting in 1531 samples collected. After controlling for missing data and eliminating outliers, 1424 samples were finally used for analysis, representing an effective sampling rate of 93.1 %.

Table 1 shows the parameters of the samples. While there are no significant differences between respondents in bungalows and in buildings in terms of gender, age, and education level. There is a difference in the annual income of families. A larger proportion of building respondents have higher incomes. Current social trends in China show that bungalow respondents mainly reside in rural or suburban areas, while building respondents mainly lived in cities. The income difference reflects the current urban-rural binary difference.

4. Results

4.1. Measurement invariance assessment of composite model (MICOM)

The measurement invariance assessment of the composite model (MICOM) is a research method based on the grouping comparison of structural equation models. Its purpose is to test whether two groups of respondents interpret the survey questions differently owing to their cultural backgrounds, identities, or racial differences. This method involves three steps to determine the comparability of questionnaire items between different groups:

Calculate the test for structural invariance. This step confirms whether different groups have the same structural and factor parameter coefficients, ensuring structural invariance. In Tables 2 and 3, four outcomes are calculated, including (a) Cronbach's α, (b) Combination reliability greater than or equal to 0.7, (c) Average variance extraction (AVE) value greater than or equal to 0.5, and (d) Heterogeneity-element ratio less than 0.9.

Calculate the component invariance score. This step assesses whether the components in the model (six constructs) show invariance among different groups. It creates the original correlation in Table 4. The closer the correlation is to 1, the more homogeneous are the corresponding elements (constructs) of the two groups [70].

Calculate the mean and variance test. This step determines differences between the two sample groups by testing the mean and variance [71]. In this study, there is no evidence that living in buildings and bungalows produces cultural and identity differences. Owing to the uniform cultural foundation of China, the questionnaire items are not understood differently, despite different regions having different characteristics and living habits. Unlike immigration countries like the United States, which have a richer cultural diversity than China [72], this may lead to different understandings of the same issues. Given this context, we can conclude that the first two steps are sufficient to prove the data collected from bungalow respondents are comparable to the building respondents.

4.2. Inspection of the structural model

The variance inflation factor (VIF) measures multicollinearity between exogenous structures. A VIF value less than 3.30 indicates no multicollinearity in this study. As presented in **Appendix S3**, the standardized root mean square residual (SRMR) is used to evaluate the fitting degree of the entire model. $SRMR<0.1$ means acceptable, while the stricter standard is $SRMR< 0.08$ [62]. Squared Euclidean distance (d_ULS) and Geodesic distance (d_G) are proposed by Dijkstra and Henseler [73,74], with $d\_ULS<0.95$ and $d\_G < 0.95$ suggested. In this study, for the bungalow respondents: $SRMR = 0.060$, $d\_ULS = 0.679$, $d\_G = 0.281$; and for the building respondents: $SRMR = 0.056$, $d\_ULS = 0.605$, $d\_G = 0.271$. Thus, the fit results of this model are acceptable. According to the result of the statistical test, the model has some reference value for the two questions in this study. Based on the model, we will test each of the assumptions and answer the two questions posed in the introduction. As part of our policy recommendations, we will also make recommendations on these questions.

Table 1
Sample structure.

Variable	Attributes	Bungalow respondents (n = 684)	Building respondents (n = 740)	Total (n = 1424)
Gender	Male	344 (50.3 %)	388 (52.4 %)	732 (51.4 %)
	Female	340 (49.7 %)	352 (47.6 %)	692 (48.6 %)
Age	25–30yrs	186 (27.2 %)	259 (35.0 %)	445 (31.3 %)
	31–36yrs	241 (35.2 %)	216 (29.2 %)	457 (32.1 %)
	37–42yrs	184 (26.9 %)	161 (21.8 %)	345 (24.2 %)
	43yrs and above	73 (10.7 %)	104 (14.1 %)	177 (12.4 %)
Education level	Technical school or below	274 (42.9 %)	299 (40.4 %)	573 (41.2 %)
	Bachelor's degree	374 (51.7 %)	401 (54.2 %)	775 (54.4 %)
	Master's degree and above	36 (5.5 %)	40 (5.4 %)	76 (5.3 %)
Average Annual Household Income	USD 1671 or below	157 (23.0 %)	40 (5.4 %)	197 (13.8 %)
	USD 1672–4179	150 (21.9 %)	73 (9.9 %)	223 (15.7 %)
	USD 4180–6965	213 (31.1 %)	245 (33.1 %)	458 (32.3 %)
	USD 6966–13,930	75 (11.0 %)	172 (23.2 %)	247 (17.3 %)
	USD 13931 and above	89 (13.0 %)	210 (28.4 %)	299 (21.0 %)

Table 2
Discriminant reliability analysis.

Variable	Bungalow respondents (n = 684)						Building respondents (n = 740)					
	PA	II	PBC	PG	PR	SN	PA	II	PBC	PG	PR	SN
PA	0.860						0.867					
II	0.256	0.852					0.008	0.829				
PBC	0.136	0.309	0.868				0.054	0.000	0.824			
PG	0.081	0.021	0.182	0.841			0.171	0.054	0.220	0.866		
PR	0.098	0.194	0.244	0.182	0.868		0.172	0.092	0.091	0.186	0.853	
SN	−0.051	0.074	0.095	−0.070	−0.001	0.698	−0.004	−0.105	−0.096	0.007	0.032	0.754

Note: The value on the diagonal is the square root of AVE, and the remaining values are the correlation coefficients with other factors.

Table 3
Heterogeneous–elemental ratio analysis.

Variable	Bungalow respondents (n = 684)						Building respondents (n = 740)					
	PA	II	PBC	PG	PR	SN	PA	II	PBC	PG	PR	SN
PA												
II	0.300						0.062					
PBC	0.161	0.367					0.076	0.048				
PG	0.087	0.067	0.21				0.196	0.068	0.254			
PR	0.119	0.233	0.29	0.221			0.193	0.113	0.101	0.224		
SN	0.065	0.077	0.146	0.076	0.055		0.077	0.114	0.136	0.074	0.091	

Table 4
Factor invariance analysis.

Variable	Original Correlation	Correlation Permutation Mean	5.0 %	Permutation *P*-Value
II	0.990	0.996	0.987	0.102
PA	1.000	0.995	0.985	0.937
SN	0.839	0.698	0.087	0.560
PBC	0.993	0.997	0.990	0.115
PG	0.991	0.996	0.987	0.123
PR	0.996	0.997	0.991	0.303

4.3. Results for bungalow respondents

Table 5 presents the supported and non-supported hypotheses for bungalow respondents. Among the 19 hypotheses, 8 were supported (H1, H3, H7, H8, H11, H16, H17, and H19), while 11 were not (H2, H4, H5, H6, H9, H10, H12, H13, H14, H15, and H18). Fig. 2 visually illustrates the results. The results are divided into three parts: Part one examines the impact of the TPB elements (PA, SN, and PBC) on II, revealing significant effects of PA and PBC ($\beta H1 = 0.217$, significant; $\beta H3 = 0.255$, significant), but non-significant effect of SN ($\beta H2 = 0.057$, not significant) on bungalow respondents' willingness to adopt residential PV. Part two explores the direct impact of policy variables (PG and PR) on II, revealing that PG does not have a direct impact ($\beta H4 = -0.062$, not significant), while PR has a significant direct effect ($\beta H8 = 0.121$, significant). Part three: The indirect and total effects of policy variables (PG and PR) on II. This includes the indirect effect of PG (H12, H14, H16) and its corresponding total effect (H18) as well as the indirect effect of PR (H13, H15, H17) and its corresponding total effect (H19). Only hypotheses H16, H17 and H19 are significant. The PBC is the only mediating variable that is capable of acting as a mediating factor, neither PA nor SN. H8 and H19 suggest that economic incentives, particularly subsidies, play a crucial role in encouraging residential PV adoption.

Fig. 2 illustrates the impact of promotion policies on the installation willingness of bungalow resident respondents. Bungalow respondents, having independent control over their roofs and walls, can decide whether to install the residential PV system. PA towards residential PV power generation systems is positive (H1). The conditions for the installation of residential PV systems depend mainly on whether the respondents have sufficient economic capacity and the technical readiness for installation, operation, and maintenance of the system, making PBC significant (H3). The effect is even larger than that of PA and SN ($\beta H3 > \beta H1 > \beta H2$). Moreover, PG and PR can further strengthen respondents' self-confidence and positively affect their II through PBC (H16, H17). Furthermore, as rational people, bungalow respondents will also consider the actual advantages and disadvantages associated with the decision scenarios they face. Therefore, PR can directly and positively influence respondents' II (H8), and the overall indirect effect of PR is more significant (H19).

4.4. Results for building respondents

Among building respondents, Table 6 supports three hypotheses: H5, H7, and H10, and the following hypotheses are not be

Table 5
Hypothesis Test Results of Bungalow respondents.

Hypothesis	Influence Path	Bungalow respondents (n = 684)			
		Path Coefficient (Significance)	*t*-value	*p*-value	Hypothesis Test results
H1	PA→II	0.217 (***)	3.995	0.000	s
H2	SN→ II	0.057 (ns)	0.698	0.485	ns
H3	PBC → II	0.255 (***)	4.943	0.000	s
H4	PG →II	−0.062 (ns)	1.069	0.285	ns
H5	PG →PA	0.065 (ns)	0.968	0.333	ns
H6	PG→SN	−0.072 (ns)	0.685	0.494	ns
H7	PG→PBC	0.143 (*)	2.349	0.019	s
H8	PR→II	0.121 (*)	2.184	0.029	s
H9	PR→PA	0.086 (ns)	1.356	0.175	ns
H10	PR→SN	0.012 (ns)	0.143	0.887	ns
H11	PR→PBC	0.218 (***)	3.861	0.000	s
H12	PG→PA→II	0.014 (ns)	0.908	0.364	ns
H13	PR→PA→II	0.019 (ns)	1.244	0.214	ns
H14	PG→SN→II	−0.004 (ns)	0.513	0.608	ns
H15	PR→SN→II	0.001 (ns)	0.095	0.925	ns
H16	PG→PBC→II	0.036 (*)	1.997	0.046	s
H17	PR→PBC→II	0.056 (**)	2.772	0.006	s
H18	PG→II (Total indirect effect)	0.046 (ns)	1.824	0.069	ns
H19	PR→II (Total indirect effect)	0.075 (**)	2.944	0.003	s

Note: S means support; ns means non-support.
***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.

supported, namely H1, H2, H3, H4, H6, H8, H9, H11, H12, H13, H14, H15, H16, H17, H18, and H19. The inspection results are categorized according to the method in 4.3. The part one involves hypotheses H1, H2, and H3, with all testing results being non-significant. This indicates that for building respondents, PA, SN, and PBC towards residential PV systems do not significantly impact their II. The part two involves hypotheses H4 and H8, representing the direct effects of PG and PR on II. Both hypotheses are non-significant, indicating that economic incentives and government subsidy policies do not directly affect II for building respondents. The part three involves hypotheses related to the indirect and total effects of policy variables (PG and PR) on II of building respondents. This includes the indirect effects of PR (H13, H15, H17) and its corresponding total effect (H19), as well as the indirect effect of PG (H12, H14, H16) and its corresponding total effect (H18). None of these assumptions are significant. Only hypotheses H5, H7, and H9 are significant. H5 represents the impact of guiding policies on attitudes, H7 indicates the role of PG in controlling PBC, and H9 shows the role of PR in PA. These three paths indicate policy variables can have a certain impact on building respondents' internal motivation. However, they do not translate into building respondents' willingness to install residential PV systems.

Fig. 3 illustrates the influencing factors and path analysis of the impact of incentive measures on respondents' willingness to install. For the surveyed householders, the decision to install residential PV systems is made by the community owners' congress. Therefore, the II of residential PV systems was not positively answered by the surveyed building owners, and thus PA, SN, PBC, PR, and PG cannot be transformed into II. PR and PG can improve the PA of building respondents to install residential PV systems (H5, H9), and PG can positively affect PBC (H7). The community owner congress and related installation requirements are the most important influencing factors that hinder respondents' willingness to install. Additionally, most of the building respondents live in cities, especially office workers and independent contractors. The domicile of most building respondents are distinct from their work or production activities. Installing residential PV systems would make their lives more insecure, and they do not want to accept that either, nor are they

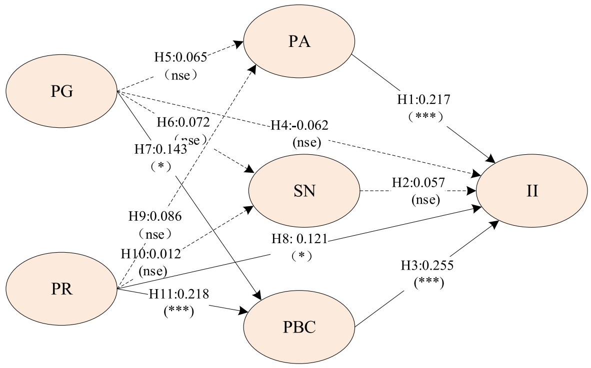

Fig. 2. Influencing Factors and Paths Analysis of residential Photovoltaic System Installation Willingness of Bungalow respondents.
Note 1
***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.
"nse" means no significant effect.
Note 2
→ shows the path is significant; ⇢ shows the path is not significant.

enthusiastic about the installation of such systems.

4.5. Results of the comparative analysis

The comparative analysis between bungalow and building respondents is shown in Table 7, where the path difference represents $\beta_{\text{bungalow respondents}}$- $\beta_{\text{building respondents}}$, and the paths with significant differences are: PA→II, PBC→II, PR→PBC→II, and PR→II, corresponding to hypotheses H1, H3, H17, and H19, respectively. $\Delta\beta_{PA\rightarrow II} = 0.231$ and $\Delta\beta_{PBC \rightarrow II} = 0.284$ suggest that bungalow respondents are more likely to install and use residential PV system than building respondents. $\Delta\beta_{PR \rightarrow PBC \rightarrow II} = 0.057$ indicates that for bungalow respondents, the path coefficient of the indirect effect of economic incentive policies on II through PBC is more significant. $\Delta\beta_{PR \rightarrow II \text{ (total indirect effect)}} = 0.082$ indicates that bungalow respondents are more indirectly affected by economic incentive policies than building respondents. The indirect impact of PR on II benefits bungalow respondents, while PR has a transformative effect on PG. However, since PG does not directly affect II, it can only be mediated by PBC.

Both bungalow and building respondents show similarities in their response to government demonstration, promotion, and consultation, which can reduce their concerns about installing PV systems on residential buildings. Among the bungalow respondents, PBC stands out as the most important factor in their decision to install a PV system on their property. When considering the willingness of bungalow residents to install a PV system, PG and PR should take PBC into account. Bungalow residents' inclination to install PV systems is primarily determined by their economic conditions, knowledge and PV system maintenance. Government subsidy and guidance policies can effectively increase their willingness to adopt residential PV.

Building respondents expressed that the three elements of the TPB (PA, SN, and PBC) had little impact on their willingness to install residential PV systems. For them, the decision to install PV systems cannot be determined solely based on the community owners' congress. It depends on clear information regarding costs, risks, benefits, and other relevant issues related to the installation of residential PV systems.

4.6. The influence of demographic characteristics on the installation intention

We performed independent-samples *t*-tests and variance analysis for both groups of respondents (in Table 8). The study examines how gender, age, education level, and average annual household income influence II. Interestingly, age does not significantly influence installation intention of both bungalow and building respondents. The average annual household income emerges as the most significant factor affecting II of both groups, with a negative impact. Among both type respondents, it is observed that women are more likely to install residential PV systems compared to men. Additionally, respondents with a bachelor's degree show a higher inclination towards installation, while those with a technical school degree or lower, as well as those with a master's degree or higher, demonstrate a lower intention to do so. In contrast, respondents with a bachelor's degree show more optimism compared to those with other degrees. In general, respondents of both bungalows and buildings perceive install residential PV systems as investment behaviors.

5. Discussion

For bungalow respondents, PA and PBC's impact on II is more significant, therefore it is easier to decide whether to install a residential PV system. Two policy perceptions (PG, PR) positively affect II through PBC and also enhance the significance of bungalow

Table 6
Hypothesis Test Results of Building respondents.

Hypothesis	Influence Path	Building respondents (n = 740)			
		Path Coefficient (significant)	*t*-value	*p*-value	Hypothesis Test Results
H1	PA→II	−0.014 (ns)	0.231	0.818	ns
H2	SN→ II	−0.111 (ns)	1.223	0.221	ns
H3	PBC → II	−0.029 (ns)	0.42	0.674	ns
H4	PG →II	0.046 (ns)	0.728	0.467	ns
H5	PG →PA	0.144 (*)	2.353	0.019	s
H6	PG→SN	0.001 (ns)	0.007	0.994	ns
H7	PG→PBC	0.210 (***)	3.902	0.000	s
H8	PR→II	0.092 (ns)	1.436	0.151	ns
H9	PR→PA	0.145 (*)	2.511	0.012	s
H10	PR→SN	0.032 (ns)	0.403	0.687	ns
H11	PR→PBC	0.052 (ns)	0.861	0.389	ns
H12	PG→PA→II	−0.002 (ns)	0.207	0.836	ns
H13	PR→PA→II	−0.002 (ns)	0.217	0.828	ns
H14	PG→SN→II	0.000 (ns)	0.007	0.995	ns
H15	PR→SN→II	−0.004 (ns)	0.353	0.724	ns
H16	PG→PBC→II	−0.006 (ns)	0.389	0.697	ns
H17	PR→PBC→II	−0.002 (ns)	0.254	0.800	ns
H18	PG→II (Total indirect effect)	−0.008 (ns)	0.417	0.677	ns
H19	PR→II (Total indirect effect)	−0.007 (ns)	0.474	0.636	ns

Note: S means support; ns means non-support.
***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.

respondents. In addition, PR directly and significantly affects II, and its total indirect effect is also significant. These findings align with previous research and have practical implications for the Chinese government's PV subsidy policies. For instance, Wang et al. [24] and Wang et al. [58] mentioned this phenomenon in their research [24,58], indicating that to further promote residential PV at the current stage, economic incentive policies, such as subsidies, still need to be prioritized. Li et al. [75] believe that publicity and guidance can also improve residents' willingness to install. However, efforts should be made to promote the various economic benefits of installation and use. This study further confirms the impact of economic incentives on bungalow residents' PV installation, which has important practical significance in the context of the current Chinese government's plan to subsidize PV decline. It is essential to strike a balance to maintain residents' enthusiasm for PV installation while phasing out subsidies.

For building respondents, PA, SN, PBC, PG, and PR cannot significantly affect II. PG and PR can have a positive impact on building respondents' psychological perceptions, such as enhancing their positive attitude toward residential PV equipment and influencing PBC. Therefore, residential PV equipment cannot be installed independently (a decision must be made by the owners' meeting in accordance with Chinese law). Previous studies by Wang et al. [58] and Wang et al. [24] explained the complexity of building residents installing residential PV using the theory of psychological distance and the TAM model, respectively. They suggested that building residents might have a more distant perception of residential PV and face challenges owing to incomplete property rights. While they might experience perceived usefulness, their intention to install is absent, as reflected in this study's findings.

The comparative analysis between bungalow and building respondents showed that bungalow respondents are more likely to install residential PV equipment than building respondents. In addition, bungalow respondents are more indirectly affected by economic incentive policies. In contrast to Wang et al.'s [58] conclusion, perceived usefulness was found to be an important factor in

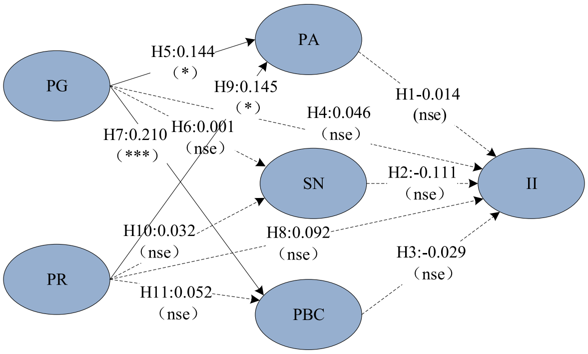

Fig. 3. Influencing Factors and Paths Analysis of Residential PV System Installation Willingness of Building respondents.
Note 1
***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.
"nse" means no significant effect.
Note 2
→shows the path is significant; ⇢shows the path is not significant.

Table 7
Comparative analysis results.

Hypothesis	Influence Path	Comparative Analysis	
		Path Difference	*p*-Value
H1	PA→II	0.231 (**)	0.008
H2	SN→ II	0.168 (ns)	0.189
H3	PBC → II	0.284 (**)	0.002
H4	PG →II	−0.108 (ns)	0.194
H5	PG →PA	−0.079 (ns)	0.376
H6	PG→SN	−0.073 (ns)	0.574
H7	PG→PBC	−0.067 (ns)	0.403
H8	PR→II	0.030 (ns)	0.724
H9	PR→PA	−0.059 (ns)	0.484
H10	PR→SN	−0.020 (ns)	0.876
H11	PR→PBC	0.166 (ns)	0.051
H12	PG→PA→II	0.016 (ns)	0.366
H13	PR→PA→II	0.021 (ns)	0.228
H14	PG→SN→II	−0.004 (ns)	0.760
H15	PR→SN→II	0.004 (ns)	0.723
H16	PG→PBC→II	0.042 (ns)	0.063
H17	PR→PBC→II	0.057 (**)	0.001
H18	PG→II (Total indirect effect)	0.055 (ns)	0.098
H19	PR→II (Total indirect effect)	0.082 (**)	0.005

Note: S means support; ns means non-support.
Note 2: Path difference = $\beta_{\text{bungalow respondents}}$- $\beta_{\text{building respondents}}$.
***$p < 0.001$.
**$p < 0.01$.
*$p < 0.05$.

promoting bungalow respondents' PV installations. They did not find that bungalow respondents had a "love and fear" effect on installing residential PV. In order to gain a deeper understanding of the differences in the impact of individual characteristics on installation intentions between bungalow and building respondents, this study explores the relationship between consumer gender, age, education level, and average annual household income on II. First, women are more likely to install residential PV systems compared to men, as building owner conventions influence whether residential PV systems can build. Women tend to be more open-minded and optimistic about the II of the community owners' convention. On the other hand, women place greater emphasis on their families, and some homemakers fall within this category. By installing residential PV at home, women expect personal benefits without needing to work for additional income. Second, age does not significantly influence installation intention of both bungalow and building respondents. Third, Respondents with a bachelor's degree show a higher inclination towards install residential PV system, this could be attributed to their relatively lower education level in comparison to residents with a master's degree or higher, along with their limited social experience when compared to people with technical school degrees or below. Last, the average annual household

Table 8
t-Test and Variance Analysis of Bungalow and Building respondents.

Variables	Attributes	Bungalow respondents (n = 684)					Building respondents (n = 740)				
		Mean	Standard Deviation	95 % Confidence Interval		Sample Size	Mean	Standard Deviation	95 % Confidence Interval		Sample Size
				Down	Up				Down	Up	
Gender	Male	2.900	1.238	2.697	3.102	344	3.581	1.103	3.424	3.737	388
	Female	2.714	1.194	2.529	2.899	340	3.809	0.936	3.661	3.956	352
	t-value	1.791					4.241				
	p-value	0.182					0.040				
Age	25–30 years	2.846	1.222	2.577	3.114	186	3.574	1.043	3.395	3.753	259
	31–36 years	2.731	1.143	2.514	2.948	241	3.781	1.000	3.587	3.974	216
	37–42 years	2.807	1.251	2.534	3.080	184	3.724	1.039	3.485	3.963	161
	43 years and above	2.912	1.379	2.431	3.393	73	3.711	1.115	3.344	4.077	104
	f-value	0.250					0.851				
	p-value	0.861					0.467				
Education Level	Technical school or below	2.891	1.265	2.674	3.109	274	3.560	1.079	3.379	3.742	299
	Undergraduate	2.698	1.194	2.511	2.885	374	3.806	0.985	3.666	3.945	401
	Postgraduate or above	3.078	0.983	2.573	3.584	36	3.316	1.103	2.784	3.847	40
	f-value	1.379					3.570				
	p-value	0.253					0.029				
Average Annual Household Income	USD 1671 or below	3.222	1.121	2.947	3.498	157	4.392	0.338	4.218	4.566	40
	USD 1672–4179	2.880	1.227	2.617	3.143	150	3.816	0.805	3.510	4.122	73
	USD 4180–6965	2.708	1.235	2.448	2.968	213	3.862	0.941	3.693	4.032	245
	USD 6, 966–13,930	2.707	1.210	2.278	3.136	75	3.608	1.129	3.357	3.859	172
	USD 13,931 and above	2.127	1.028	1.769	2.486	89	3.378	1.108	3.163	3.594	210
	f-value	5.115					5.647				
	p-value	0.001					0.000				

income of both groups negatively impacts II. This indicates that respondents would treat the installation action as investment behavior. Owing to the limited profits the systems can generate (e.g., building residents can save on electricity costs, while bungalow residents can earn additional electricity fees), the installation actions are less attractive to higher income groups. This study found that residents' willingness to install is influenced by multiple factors and exhibits differences under different living conditions. These research results have significant reference value for promoting residential PV popularization and application in Northern China.

This study extends TPB model by confirming its three core elements: PA, SN, and PBC, which influence residents' decision on whether to install residential PV systems. Additionally, residents' decisions will be influenced by external policy forces and their living conditions as well. Compared to previous studies that only considered internal factors [31,35–38], the updated model in this study combines internal and external factors, promoting the development and progress of the environmental science and energy policy fields. In addition to helping achieve energy transformation goals and reducing carbon emissions, it can also contribute to building a sustainable society and environment. The TPB model provides a comprehensive framework that can be used to better understand and predict people's behavior and motivations when installing residential PV. By understanding PA, SN, and PBC, targeted intervention strategies can be formulated to enhance people's enthusiasm for making more environmentally friendly decisions when installing residential PV systems. Considering that TPB model has further expansion space, refer to the Hsu et al. [41] and Liobikien ė et al. [42] approach. Factors such as energy prices and socio-cultural could be combined with the TPB model to further explore the impact mechanism of these factors on residents' willingness to install residential PV systems, and comprehensively evaluate the impact of these factors on residents' willingness to install.

6. Conclusion

This study employs the TPB model and policy path model to elucidate the significant factors influencing residents' behavioral intentions to purchase and install residential PV systems in three typical provinces. The research also examines the impact of the "subsidy recession" on the willingness to adopt residential PV through statistical modeling, confirming its negative effect on PV installation considering changes in living conditions through group comparisons. The results indicate that PV promotion is effective only among bungalow respondents. Among bungalow respondents PR affect II more than PG ($\beta H19 = 0.075 > \beta H18 = 0.046$), and both PR and PG can indirectly affect II through PBC ($\beta H17 = 0.036$, $\beta H16 = 0.056$, significant). PBC, as a critical mediated variable, had a "love and fear" effect on installing residential PV among bungalow respondents. To achieve more comprehensive results, policies need to be adapted to local conditions and actual policies need to be tailored to the specific situation of the target residents. Therefore, the following recommendations are made to promote the healthy development of the PV industry in China:

Building residents can consider partnering with third-party companies to help occupants overcome obstacles to installing PV systems. By leasing roofs, walls, and other shared resources of the buildings, residents will be more inclined to maintain these common areas during owners' conventions, especially when they receive a fixed rental income with no additional costs. Subsidies can be directly provided to third-party contractors, who can conduct effective publicity and demonstrations, potentially yielding a greater impact than government-led initiatives. Bungalow residents may be able to increase their incomes and create employment opportunities through residential PV systems. To achieve the effect of coordination and promotion, the "PV + agriculture" mode, integrating agriculture, forestry, animal husbandry, and fishing with PV systems, could be adopted by bungalow respondents. The PV systems can gradually reduce its dependence on government subsidies and promote sustainable development.

This study has several limitations. First, it only uses data from Hebei, Shandong, and Henan provinces in China. Although the penetration rate of residential PV is the highest in these three provinces, the technical and economic benefits of installing residential PV in these three provinces are also the highest [75]. The lifetime of residential PV in China is usually more than 20 years, which makes the installation of PV systems on residential buildings more economically attractive [76]. Second, owing to epidemic control implemented as a result of COVID-19 measures, this study collected data through online surveys. People aged 43 years and older are less inclined to use cell phones and other communication tools to participate in online surveys, resulting in only 10.7 % of respondents being over 43 years old. Based on data from the seventh Chinese census released in 2021, an estimated 18.7 % of the population is over 60, and 13.5 % is over 65 [77]. Consequently, this study does not fully reflect the attitudes and opinions of the older generation towards residential PV generations. In the future, a more comprehensive survey that includes both online and offline respondents is anticipated to improve the accuracy of research results. Policymaker may contemplate implementing a differentiation strategy for PV promotion, taking into account the unique characteristics of various regions in China.

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Data availability

Data will be made available on request.

CRediT authorship contribution statement

Jiaxi Wu: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Writing – original draft. **Shali Wang:** Investigation, Software, Validation, Writing – original draft. **Zheng Meng:** Data curation, Formal analysis, Investigation, Resources, Writing – review & editing. **Rui Zhang:** Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix T. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e20891.

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