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Social network and villagers' willingness to adopt residential rooftop PV products: A multiple mediating model based on TAM/PR theory

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Facing the promise of "carbon neutrality" and "carbon peak", China's vast rural areas will be the main front of energy conservation and emission reduction in the future. From the perspective of social capital, this paper combined TAM and perceived risk theory to construct a hypothesis model. Based on 617 rural survey data, structural equation model was used to reveal the influencing factors of the willingness to adopt residential rooftop PV products in rural China. The results show that: 1) social network has a significant impact on the willingness of villagers to adopt rooftop PV products. 2) Perceived usefulness, perceived ease of use and perceived risk play multiple mediating roles. 3) The parallel mediating effect of villagers' perceived risk on the relationship between social network and adoption intention is much higher than the other two paths. 4) The chain mediating effect of perceived risk and perceived ease of use on the relationship between social network and villagers' adoption intention is much higher than the other two paths. This study provides rich policy implications for rural renewable energy promotion and energy transition in China and other developing countries.

KEYWORDS

solar technology adoption, social network, photovoltaic products, sustainable development, rural China

1 Introduction

Renewable energy plays a key role in poverty reduction and sustainable development in many developing countries (McCollum et al., 2018). Promoting affordable clean energy is not only an explicit goal of the sustainable development goals, but also intersects with other areas such as achieving greater human well-being and building resilient infrastructure (Sovacool and Ryan, 2016). In recent years, advances in solar technology have reduced the cost of photovoltaic products, creating unprecedented opportunities to produce affordable electricity while minimizing environmental

pollution (Lewis, 2016). The Energy Ladder Model and Energy Stacking Model clearly reveal the close connection between household wealth and Energy consumption (Yadav and Davies, 2021).

Rooftop photovoltaics is one of the industries that has received a lot of policy and financial support in China's poverty alleviation campaign in recent years[1]. Building on existing policies on poverty reduction and renewable energy development, the Office of leading Group for Poverty Alleviation and Development (OPAD) and the National Energy Administration (NEA) have proposed a plan to build photovoltaic infrastructure to support targeted poor households in poor areas of China. Subsequently, the Chinese government announced the Photovoltaic Poverty Alleviation Project (PPAP) in March 2016, covering 471 poverty-stricken counties in 16 provinces[2], and approved two rounds of photovoltaic infrastructure construction plans in 2016 and 2017 respectively[3]. In 2019, all the PPAP projects under the TPA plan will be connected to the grid, and the power generation income will support two million households in 35,000 poor villages across the country. Up to now, photovoltaic poverty alleviation has been widely regarded as an important means of poverty alleviation with remarkable results (Zhang et al., 2020). As a "Granular technology", household distributed photovoltaic not only has strong emission reduction potential (Wilson et al., 2020), but also helps to save farmers' time cost, promote health and poverty reduction and other sustainable goals, and the Chinese government has always emphasized its "pivotal" position[4]. However, the promotion of these projects has been greatly limited, mainly due to the user side, namely the villagers (Li B. et al., 2021). Even from the national level, these projects are beneficial to increasing income, but due to various complex factors, villagers are not willing to adopt residential rooftop photovoltaic, and the factors behind it are worth exploring.

Promoting residential rooftop pv technology and products in rural areas will not only help China achieve its commitment of "carbon peak" and "carbon neutral", but also help increase rural incomes and alleviate poverty. As the main producer, the willingness of villagers to adopt residential rooftop PV

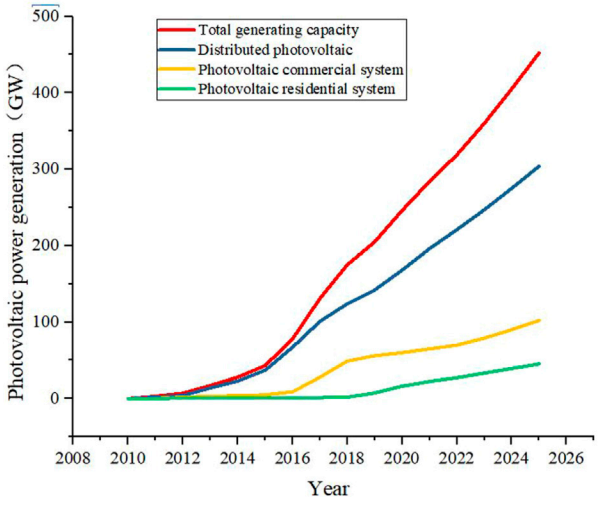

FIGURE 1
Generation capacity of various pv systems in China from 2010 to 2025.

products is a key factor affecting rural photovoltaic power station development, land use and rooftop PV promotion rate. Unfortunately, current research has not focused on the micro producers, namely rural residents. However, it is still dominated by many production enterprises or large industrial and commercial distributed rooftop PV. As a result, the installed scale and speed of residential rooftop distributed PV in China still cannot compare with that of large photovoltaic power stations and industrial and commercial enterprises. Based on the data of the International Energy Agency (IEA), we find that China's residential PV system only accounts for one 10th of the total electricity generation (see Figure 1). In addition, the installation progress of all provinces varies greatly, and the number of installations in most provinces is still small (see Figure 2). Therefore, it is particularly important to explore the main factors affecting the adoption of rooftop PV by rural residents, which is the key to the successful promotion of rooftop PV products in rural areas. Therefore, it is particularly important to explore the main factors influencing the adoption of rooftop PV by rural residents.

The main contributions of this study include: 1) It starts from the farmers as a micro-subject, and carries out research on the basis of pre-investigation, so as to dig out more influencing factors based on rural social network and expand the research on social network. 2) This study combines photovoltaic credit, a typical financial technology, with rooftop photovoltaic power generation, a low-carbon technology, and proposes a rooftop photovoltaic promotion model based on photovoltaic credit. This will play an important role in promoting photovoltaic and other energy technologies in many developing countries and effectively reducing the utilization rate of energy-consuming fuels and

1 The central government is keen to use the energy transition to promote multiple goals, including climate change mitigation, technological leadership and reduction of rural poverty; By promoting "ecological civilization," the government aims to address environmental problems while rebalancing the geographic and social inequalities inherent across China (Ely et al., 2019; Liao and Fei, 2019).

2 http://www.ndrc.gov.cn/gzdt/201604/t20160401_797335.html.

3 http://zfxxgk.nea.gov. cn/auto87/201,610/t20161017_2310.htm; http://zfxxgk.nea.gov.cn/auto87/201801/t20180104_3097.htm.

4 China National Energy Administration made clear that "household photovoltaic will bear responsibility" (http://www.nea.gov.cn/2021-05/21/c_139960902.htm). To promote clean energy Power green water castle peak (https://www.ndrc.gov.cn/xwdt/ztzl/gnjnybg/202202/t20220227_1317322.html?code=&state=123)

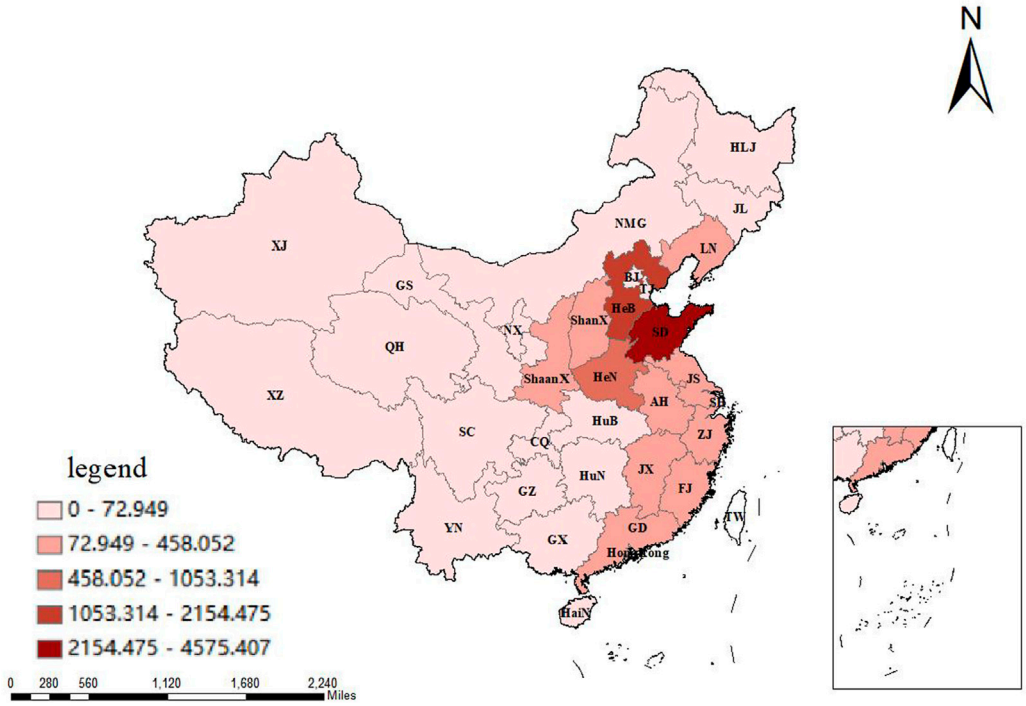

FIGURE 2
2021 Installed capacity of household PV projects in China (MW).

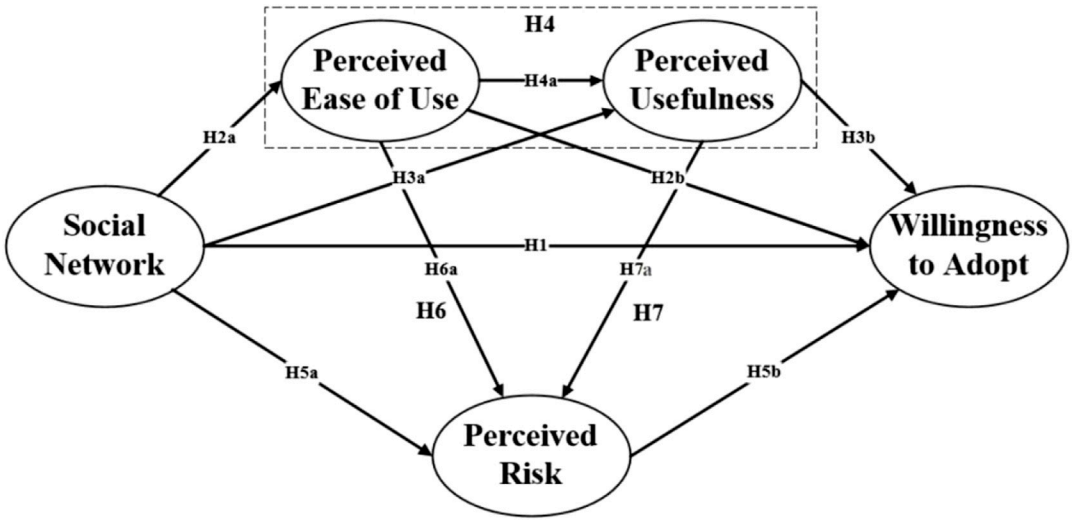

FIGURE 3
Research model.

carbon emissions in rural areas. 3) We incorporated the technology acceptance model and perceived risk theory into the model to construct multiple mediation effect analysis under the main effect of social network, and more reasonably revealed the influence mechanism of social network and villagers' willingness to adopt rooftop PV products.

2 Literature review and research hypothesis

2.1 Literature review

The necessity of studying rural rooftop PV and promoting related credit products has been unanimously recognized by the majority of scholars (Hogarth, 2012; Chaianong and Pharino, 2015; Li et al., 2017; Abdul-Salam and Phimister, 2019; Li et al., 2020). At present, how to improve farmers' adoption of photovoltaic technology and microfinance[5] is mainly studied from three aspects.

2.1.1 Rural microfinance and energy technology application

Fintech and energy access have a high degree of synergy, and the two are not independent but mutually reinforcing. The microfinance sector plays an important role in the process of energy acquisition by the poor and has great potential in the future (Groh and Taylor, 2015). Some scholars believe that the lack of credit support for energy products is an important reason for their lack of mass appeal and acceptance (Rao et al., 2009). Hogarth (2012) found that some microfinance institutions in Uganda helped traditional energy use technologies in the region become more efficient and modern through energy loan projects, and farmers installed solar home systems (SHS) through loans can effectively reduce carbon emissions in Uganda. Meanwhile, Zhang et al. (2014) believed that solar photovoltaic system can effectively reduce greenhouse gas emissions, and microfinance can effectively stimulate the promotion of photovoltaic technology. Khan et al. (2019) found that PV loan plays a decisive role in the promotion of household PV system in Bangladesh, and found that 63% of rural households effectively use household PV system through microcredit (PV loan). Newcombe et al. (2017) found that deploying solar home systems (SHS) in rural areas of Myanmar through microcredit programs. The rural poor can own SHS for a few years at $6.40 per month, which is very cost-effective for farmers. Additionally, Robert et al. (2018) evaluated the willingness of Indian farmers to accept solar lamps through the Becker-Degroot-Marschak mechanism and found that credit restriction was an important factor leading to their low willingness to accept solar lamps. Yakubu et al. (2019) also found that credit restrictions caused by market defects greatly hindered farmers' adoption of photovoltaic systems in Uganda.

2.1.2 The factors of farmers' willingness to adopt microfinance

In terms of studying factors influencing the diffusion of rural microfinance, many scholars have paid attention to the important role of rural social capital, and most of them use social network to measure social capital (Wydick and Karp, 2011; Banerjee et al., 2013; Omodei and Arenas., 2016). Some scholars start from the structural dimension of social network and study its influence mechanism. For example, Banerjee et al. (2013) studied the "diffusion centrality" of farmer microfinance from the structural dimension and found that the "Calm effect" also plays an important role in this process. Meanwhile, Omodei and Arenas. 2016 also defined a new point centrality to measure the promotion of microfinance in rural India from the structural dimension, and found that the multi-layered social network is a key trigger factor for the promotion of microfinance. However, more scholars explored the influence mechanism of social network from the relational dimension. Pride and Milroy (1980) proposed that social network was formed by interconnected individuals on the basis of informal social relations, which indicated that social network was a kind of relationship network to a certain extent, and social relations such as neighbors, friends and relatives all affected farmers' behavioral decisions. Meanwhile, Wydick and Karp, 2011 believed that interpersonal relationship played an important role in farmers' access to credit, especially in developing countries. He believed that the co-existence of "correlated effect" and "contextual effect" in rural communities will construct rural social networks and show that the powerful rural "peer effect" has a key influence on farmers' acceptance of credit. Okello et al. (2020) found that social networks played a full intermediary role between financial literacy and financial inclusion of farmers, and used structural equation model to test, proving that the social ties of farmers were an important channel for spreading financial knowledge. The problem of credit diffusion can be transformed into the problem of financial information diffusion to some extent (Okello et al. (2018); Cole et al., 2011), and social network plays a huge role in helping rural financial information diffusion (Okten and Osili, 2004; Balatti, 2007; Lusardi et al., 2014). Therefore, it is important to study the influence of social network on farmers' photovoltaic loans.

However, in China, photovoltaic loans and photovoltaic system are closely integrated, they constitute a fusion of photovoltaic products. So it is not enough to only explore the influencing factors of farmers' photovoltaic loans (a kind of microfinance). It is also necessary to deeply explore the influencing factors of villagers' photovoltaic installation willingness and integrate these factors. On the one hand, to ensure that variables are as complete as possible. On the other hand, ensure that the factors influencing the willingness of rural residents to adopt photovoltaic products (including photovoltaic loans) are fully identified.

5 Microfinance refers to continuous credit services that provide small amounts to the middle and low income groups. Combined with rural China, PV installation requires a large amount of capital, so supporting credit services are necessary. Most provinces in China have developed photovoltaic loans, a type of microfinance typically used to help rural residents install rooftop photovoltaics

2.1.3 The factors of farmers' willingness to adopt energy technology

At present, the willingness of farmers to adopt energy technology is mostly concentrated at the macro level. Economic factors such as investment cost, investment income and payback period are often regarded as some of the most critical factors (Zhang et al., 2012; Vasseur and Kemp, 2015; Qureshi et al., 2017; Zander et al., 2019). Related to this, some economic incentive policies are emphasized, such as photovoltaic installation subsidies, feed-in tariffs (FIT), tax credits, etc. (Groote et al., 2016; Briguglio and Formosa., 2017; Nicolini and Tavoni, 2017).

However, there are relatively few studies on farmers' willingness to accept photovoltaic technology from the perspective of society. The existing social factors include social interaction, social contagion and social norms (Bollinger and Gillingham, 2012; Andrea et al., 2017; Nicolini and Tavoni, 2017; Alrashoud and Tokimatsu, 2020). Similarly, lack of information is also one of the important reasons for the difficult implementation of photovoltaic technology (Jager, 2006; Wang et al., 2018). In the United States, solar Community Organizations (SCOs) provide information to generate social interaction to increase the willingness of residents to adopt residential solar photovoltaic technology, which can be summarized as "peer effects" to some extent (Noll et al., 2014). Wang et al. (2018) found that, in fact, the impact of social network on farmers' PV system can be summarized as another social response, namely "herd effect", and the extension of social network can be explained by another concept, namely "opinion leader". Opinion leaders play a core role in social networks (Matous and Wang, 2019), and they are actually a type of imperceptible social influence, influencing the practices of others around them through word of mouth (Cheung et al., 2009). Yamamoto (2015) found that opinion leaders play an important role in the dissemination of new technologies in the study of Japanese photovoltaic system promotion, and the promotion and adoption of technologies are promoted to a certain extent through informal information sharing. Or it can be said that the person who accepts the technology first proves the feasibility of the technology, thus becoming a role model and influencing others (Schelly, 2014).

Notably, Social network is not the only influencing factor. Based on the characteristics of farmers and the technical and risk analysis of photovoltaic mode, the perception characteristics of farmers must also be considered (Alam et al., 2011). Many studies have incorporated the technology acceptance model (TAM)[6] into the research of farmers' willingness (Broman et al., 2014; Zhou and Abdullah, 2017; Peng et al., 2021), and concluded that perceived usefulness and perceived ease of use play an important role. At the same time, many studies have shown that farmers' perceived risk is an important factor affecting their willingness to accept green technology (Wang et al., 2019; Arning et al., 2020), and for different technological products, perceived risk plays different roles (Li L. et al., 2021). Therefore, it is worth discussing whether perceived risk plays a role in photovoltaic technology.

To sum up, the deficiencies of existing studies and the literature gaps filled by this paper are found in the above analysis and extraction. 1) Research on rural PV promotion mode is generally insufficient, and most of the relevant studies are separate studies of rooftop PV and PV loan. In fact, the two are not unrelated, on the contrary, they are complementary. Therefore, it is particularly important to integrate the two and develop a "photovoltaic technology + photovoltaic loan" mode. 2) At present, there are relatively few studies on the mechanism of social network's influence on farmers' renewable energy products. In fact, relationship dimensions and opinion leaders in social networks can exist at the same time and influence each other, thus influencing farmers' willingness. The mechanism of their influence on the integration mode of financial technology and low-carbon technology is rarely be studied. 3) Many studies independently use technology acceptance model (TAM) and perceived risk theory to analyze their impact on farmers' willingness. However, TAM can be integrated with other theories, and it will be more comprehensive to construct an integration model (TAM/PR) to measure farmers' willingness. Based on the above research limitations, this paper constructed a multiple intermediary model from the perspectives of social network and villagers' psychological perception, combined with TAM model and perceived risk theory[7], and revealed the influence mechanism of social network on villagers' willingness to adopt rooftop PV products.

2.2 Research hypothesis

2.2.1 Social networks and willingness to adopt rooftop PV products

China's countryside is a society with obvious social network characteristics. Fei (1992) pointed out that the social nature of China's rural areas is a "differential mode of association

6 According to Davis' Technology Acceptance Model (TAM), one's actual use of a technology system is influenced directly or indirectly by the user's behavioral intentions, attitude, perceived usefulness of the system, and perceived ease of the system. This model is extremely relevant to the product adoption issues that we study, so not only do we incorporate this model, but many other similar studies also apply this model

7 The theory of perceived risk was initiated by Raymond Bauer, professor of Harvard University. According to the theory, perceived risk is a sense of uncertainty in the process of product purchase caused by the consumer's inability to predict the quality of the purchase result, and the resulting unpleasant feeling, that is, the user's perception of uncertainty. Here, we combine it with the willingness of villagers to adopt rooftop photovoltaic products to analyze the role of six perceived risks

(Chaxugeju)" based on kinship and geographical relations, and such social relations have always dominated farmers' interpersonal communication. Meanwhile, the strength of the neighbor relationship plays an important role in the network relationship in rural areas. The proverb "a distant relative is better than a good neighbor" reflects the importance Chinese society attaches to the value of neighbors. It is obvious that neighbors can be used as a kind of social capital, which can help and influence the capital owner. Therefore, Social networks often play an important role in farmers' behaviors and intentions (Micheels and Nolan, 2016; Hunecke et al., 2017; Castillo and Engler, 2021; He et al., 2022). Although the aforementioned study confirmed the positive correlation between social network and behavioral intention from the aspects of agricultural technology adoption of farmers, and did not directly verify it from the perspective of green products and related financial services of farmers from the dual dimension, the following research hypotheses can be made based on the support of the above effective research results:

H1. Social network can positively promote the willingness of rural residents to adopt rooftop PV products.

2.2.2 Parallel mediating effect of TAM based villagers' perception characteristics and their willingness to adopt photovoltaic products

"Differential mode of association (Chaxugeju)" in rural China has an important impact on farmers' economic behavior and perception characteristics. Generally speaking, macro social factors tend to have an impact on micro individual factors. For example, Castillo and Engler, (2021) found that farmers' social network will affect their perceived behavioral control and subjective norms. Thus, villagers' willingness to adopt pressurized irrigation technology is promoted. Meanwhile, Merwe and Heerden (2009) pointed out that the existence of social influence plays a great role in the demand of farmers. In fact, on the one hand, social network may generate trust through accumulated shared beliefs or values within the group; on the other hand, interactive communication may bring more heterogeneous information and eliminate information asymmetry, both of which will eliminate the psychological panic of villagers.

Villagers' willingness to adopt photovoltaic products is strongly correlated with their perceived characteristics of the technology and services. Perceived usefulness refers to that users believe that using a certain system can effectively improve their work performance. Specifically, villagers believe that installing pv can effectively save electricity costs and obtain electricity sales income. Perceived ease of use refers to that users think it is easy to understand and master a certain system (Davids, 1989). Specifically, farmers think it is easy to understand photovoltaic power generation technology and be proficient in operation. Many studies have shown that there is a significant influence relationship between perceived usefulness and perceived ease of use and willingness in TAM (Vasseur and Kemp, 2015; Kardooni et al., 2016). Li B. et al. (2021) found that usefulness perception and ease of use perception played a significant role in promoting villagers' willingness to adopt photovoltaic agriculture. Most of the previous studies did not take into account the preexisting variables before perceptual characteristics. In fact, the perceived usefulness and perceived ease of use of villagers do not occur in a vacuum, and factors influencing these two latent variables must also exist. The "social network" selected in this paper can further explain the sources of perceived usefulness and perceived ease of use of villagers. Unlike the ripple effect in psychology, social network is a multidimensional index system, and it plays a decisive role in villagers' cognitive level and learning ability (Conley and Udry, 2001). Trust generated in social network and interaction formed in the network will affect villagers' perception level, and then affect the generation of their behavioral intention. Based on this, the following hypotheses are proposed:

H2. Perceived ease of use plays a mediating role between social networks and willingness to adopt.

H2a. Social network plays a positive role in promoting villagers' perception of ease of use.

H2b. Villagers' perception of ease of use has a positive impact on their willingness to adopt.

H3. Perceived usefulness plays a mediating role between social networks and willingness to adopt.

H3a. Social network plays a positive role in promoting villagers' perceived usefulness

H3b. Villagers' perceived usefulness has a positive impact on their willingness to adopt.

2.2.3 The multiple mediating effects of villagers' perceived usefulness and perceived ease of use

The perceived ease of use and perceived usefulness in TAM are not independent of each other and do not have influence. Whether it is mass users or specialized villagers, the two factors in their perception characteristics must not be completely independent, and there must be an influence mechanism between them. For photovoltaic products, since farmers are generally not highly educated, ease of use perception may be the first perception, followed by usefulness perception. The higher the ease of use of products, the performance of villagers may be improved, thus enhancing their potential perceived usefulness. While social network, a pre-latent variable, affects farmers' perceived usefulness and perceived ease of use respectively, it may also form a complete chain with the two, thus affecting farmers' willingness to adopt. For example, Taufik and Hanafia (2019)

believe that perceived ease of use can promote airport passengers' willingness to adopt self-service technology (SST) by enhancing perceived usefulness (Taufik and Hanafiah, 2019). Based on this, the following hypotheses are proposed:

H4a. Villagers' perceived ease of use plays a positive role in promoting their perceived usefulness

H4. Villagers' perceived ease of use and perceived usefulness play a chain mediating role in villagers' social network and their willingness to adopt photovoltaic products.

2.2.4 The mediating effect of villagers' perceived risk and villagers' willingness to adopt photovoltaic products

High risk and financial cost are important factors hindering the promotion of small-scale energy products. As a financial product, PV loan is a preferential financial loan service provided by commercial banks to farmers who install PV. Therefore, it is necessary to propose "perceived risk" from the perspective of villagers' psychological cognition to study villagers' willingness to adopt PV. Previous studies have pointed out that perceived risk has a significant negative impact on energy technology adoption (Arning et al., 2020; Linzenich et al., 2021). For example, Lau et al. (2020) emphasized the indispensability of revenue perception in exploring the factors of willingness to adopt solar photovoltaic technology in Malaysia. There are multiple dimensions of perceived risk. Based on the research of Stone, (1993) and Yang et al. (2015), this paper divides perceived risk into five dimensions: Functional Risk (FUNR), Social Risk (SLR), Financial Risk (FINR), Time Risk (TMR) and Psychological Risk (PLR) to measure farmers' perceived risk. At the same time, as the main source of information for farmers, social network also has a certain influence on their perceived risk. Besley and Case, (1995) believed that learning through social networks could enhance villagers' cognition of uncertain risks. In fact, on the one hand, social network may generate trust through accumulated shared beliefs or values within the group; on the other hand, interactive communication may bring more heterogeneous information and eliminate information asymmetry, both of which will eliminate the psychological panic of villagers. Although these studies are not analyzed from the perspective of villagers' willingness to accept photovoltaic products, they all show from the side that the relationship between the two does exist. Based on this, the following hypotheses are proposed:

H5. Perceived risk has a mediating effect between villagers' social network and willingness to accept photovoltaic products.

H5a. Social network has a negative impact on villagers' perceived risk.

H5b. Villagers' perceived risk has a negative impact on their willingness to adopt pv products.

2.2.5 The multiple mediating effects of villagers' perception characteristics and perceived risks based on TAM

Perceived risk often arises in the context of existing knowledge, not in a vacuum. Yang et al. (2015) found that there is indeed a certain relationship between other perceived characteristics and perceived risk. Based on the special group of rural residents and the financial service of photovoltaic loan, functional risk and emotional risk also exist. In this study, the perceived risk is divided into five dimensions to measure. Under the influence of continuous rural financial exclusion, farmers will generate financial risk perception, and the source of this risk is rural commercial banks and some other small financial institutions. However, for the other four dimensions of risk, financial institutions are obviously unable to effectively improve. Villagers' perception of functional risk and time risk is fundamentally derived from photovoltaic produced by enterprises. There is an impact between villagers' understanding of photovoltaic power generation technology and their risk perception. If the technology and principle can be understood more easily, farmers' perception of time risk and functional risk will be further eliminated. Social and psychological risks can be traced back to the villagers' cognition of whether photovoltaic power generation technology is really useful. Product usefulness will bring economic effects to villagers, which will further eliminate the villagers' perceived risks. In rural areas, the demonstration effect of opinion leaders plays an important role (Merwe and Heerden, 2009), which will be presented to other residents as a carrier of the usefulness of photovoltaic installation. Therefore, while social networks influence villagers' perceived usefulness through demonstration effect, they will further eliminate villagers' risk perception, especially social and psychological risk perception, and ultimately affect villagers' adoption intention. Based on this, the following hypotheses are proposed:

H6a. Perceived ease of use has a negative impact on villagers' perceived risk.

H6. Perceived ease of use and perceived risk play a chain mediating role between social network and willingness to adopt photovoltaic products.

H7a. Perceived usefulness has a negative impact on villagers' perceived risk.

H7. Perceived usefulness and perceived risk play a chain mediating role between social network and willingness to adopt photovoltaic products.

Based on the above analysis, the research model of this paper is shown in Figure 3:

3 Research methods and data

3.1 Research methods

This paper mainly selects four latent variables, namely social network, perceived risk, perceived usefulness and perceived ease of use, to explore the influence mechanism of them on villagers' willingness to adopt photovoltaic products. Since social network and perception characteristics are potential variables with many dimensions that are difficult to measure directly, and there may also be multicollinearity among these potential variables, these problems are difficult to be solved by Logistic model and Probit model, but structural equation model (SEM) can better solve the above problems. Moreover, SEM can deal with the relationship between multiple independent variables and dependent variables at the same time, and allow the existence of variable measurement error, so as to help confirm the influence relationship and influence path between variables, and analyze the direct or indirect effects of their existence. Therefore, structural equation model (SEM) is adopted in this paper for analysis, and its general measurement equations can be expressed as Equ 1) and 2):

$$X = \Lambda_x \xi + \delta \quad (1)$$

$$Y = \Lambda_y \eta + \epsilon \quad (2)$$

Where, X represents exogenous observation variable, which is used to reflect various observation indicators of villagers' social network; Y represents the endogenous observation variable, which is used to reflect the index of villagers' perceived usefulness, perceived ease of use, perceived risk and willingness to adopt photovoltaic products. Λ_x and Λ_y represent the correlation coefficient matrix of the exogenous and endogenous latent variables and their observed variables respectively. ξ is the exogenous latent variable used to represent the villagers' social network. η was an endogenous latent variable, representing perceived usefulness, perceived ease of use, perceived risk and willingness to adopt. δ and ε are error terms.

Finally, the structural equation model between latent variables is:

$$\eta = A\eta + B\xi + \zeta$$

Where, A is the relationship matrix between endogenous variables, reflecting the interaction between endogenous latent variables η. B is the relation matrix of exogenous variables, reflecting the influence of exogenous potential variable ξ on endogenous potential variable η. ζ is the random error term of the structural equation.

3.2 Questionnaire design

Based on the above theoretical analysis and in order to ensure that the variables have good reliability and validity, all the measurement questions adopted in the study are based on the maturity scale and are obtained in combination with the specific research object and actual situation of this paper. At the same time, in order to prevent measurement item design form a single, high dimensions is not enough comprehensive, general moderate problem, this paper adopted the paper point of view, and more detailed measurement applied to the research of this article in the item description, expressed in improving accuracy at the same time, also can facilitate the villagers to understand, which collected the real useful information.

First, we draw on the classic studies of Nahapiet and Ghoshal, (1998), Tsai & Ghoshal, (1998), Levin and Cross, (2004) and Hunecke et al. (2017) to design social networks that emphasize trust. It effectively reflects the respondents' closeness to the group as a whole and their trust in others. Then, we combined Rogers' innovation diffusion theory and referred to the studies of Vasseur and Kemp (2015) and Kardooni et al. (2016) to design an effective scale for measurement by combining comparative advantage and complexity with perception of usefulness and ease of use. At the same time, we designed a questionnaire about perceived risk by referring to the studies of Stone, (1993), Yang et al. (2015) and Linzenich et al. (2021). All the items in the third section were measured on a five-point Likert scale:1 = completely disagree, 2 = partially disagree, 3 = basically agree, 4 = relatively agree, and 5 = strongly agree. The specific items are shown in Supplementary Appendix SA. As the research objects are rural residents, the education level and other factors are taken into account. We first translated all the English into Chinese, and made simple notes next to the questions to help them understand the meaning of the questionnaire items, so as to give the most authentic ideas.

3.3 Data sources and descriptive statistics

The data used in this paper come from the field survey of farmers in Changzhou, Yangzhou, Nantong, Suqian and Zhenjiang of Jiangsu Province in January and August 2021. We visited 29 villages in eight towns and distributed questionnaires to households and collected them in time. In the end, 653 questionnaires were sent out and 628 questionnaires were collected. After eliminating invalid questionnaires such as missing answers and inconsistent answers (random answers), 617 valid questionnaires were finally determined, including 121 in Changzhou, 110 in Yangzhou, 122 in Nantong, 147 in Suqian and 117 in Zhenjiang.

The basic information of the sample includes the gender, education level, annual income level and age of farmers. Meanwhile, considering that the Roof area and Permanent population of farmers are also related to installation conditions and electricity demand respectively, we designed "Roof area" and "Permanent household population". Specific sample information is shown in Table 1:

TABLE 1 Demographic information statistics of respondents (N = 617).

Variable	Category	Frequency	Percentage (%)
Gender	Male	290	48.7
	Female	327	51.3
Age	20–35 years old	102	17.1
	36–45 years old	130	20.8
	46–55 years old	155	26.1
	56–65 years old	156	26.2
	More than 66 years	74	9.7
Education level	Primary school and below	114	18.3
	Junior High school	171	27.6
	Senior high school/technical school	193	31.9
	Junior College	94	16.1
	Bachelor Degree or above	33	6.1
Occupation	No occupation or retired	130	21.07
	Self-employed (farming, hawker)	96	15.56
	Regular worker (in a factory)	206	33.39
	Casual worker (irregular work)	110	17.83
	Others	75	12.16
Monthly Income (RMB)	Less than 2000	78	12.4
	2001-4000	168	27.2
	4001-6000	139	22.7
	6001-8000	152	24.9
	More than 8000	80	12.8
Roof area (m^2)	Less than 40	82	13.29
	40-50	113	18.31
	50-60	191	30.96
	60-70	162	26.26
	More than 70	69	11.18
Permanent household population (person)	1	60	9.72
	2	128	20.75
	3	189	30.63
	4	166	26.90
	More than 5	74	11.99

4 Results and discussion

4.1 Reliability and validity test

4.1.1 Exploratory factor analysis (EFA)

In this paper, SPSS26.0 software was first used for exploratory factor analysis, in which the KMO value was 0.970, greater than 0.8, and the significance probability of two statistic value of Bartlett sphere test was 0.000, less than 0.005. After principal component analysis, its cumulative variance contribution rate reached 70%. It shows that the observed variable data has good validity and is suitable for factor analysis. Then, Cronbach's alpha coefficient was used to test the reliability of the model. A total of five latent variables were selected in this paper, namely, social network, perceived usefulness, perceived ease of use, perceived risk and willingness to adopt. SPSS26.0 software was used for reliability analysis, and the test results showed that, Cronbach's alpha coefficients of these five dimensions were all greater than 0.85, indicating that the scale had good reliability. The specific test results are shown in Table 2.

4.1.2 Confirmatory factor analysis (CFA)

In this paper, Amos26.0 software was used for confirmatory factor analysis (CFA) to test the convergence validity and discriminant validity of the model. Firstly, the convergence validity of the model is tested by using the combined reliability (CR) value and the average variance extraction (AVE). The test results show that the standardized factor loads of all dimensions are greater than 0.7, and are significant. The Composite Reliability (CR) is greater than

TABLE 2 Results of reliability and validity analysis.

Latent variable	Item	Std.Estimate	P	CR	AVE	Cronbach's α
SN (Social Network)	SN1	0.891	***	0.898	0.7466	0.9
	SN2	0.872	***			
	SN3	0.828	***			
PU (Perceived Usefulness)	PU1	0.844	***	0.877	0.7045	0.877
	PU2	0.84	***			
	PU3	0.834	***			
PEOU (Perceived Ease of Use)	PEOU1	0.819	***	0.862	0.6758	0.884
	PEOU2	0.839	***			
	PEOU3	0.808	***			
PR (Perceived Risk)	PLR1	0.850	***	0.958	0.6133	0.955
	PLR2	0.861	***			
	PLR3	0.830	***			
	TMR1	0.735	***			
	TMR2	0.794	***			
	TMR3	0.742	***			
	FINR1	0.734	***			
	FINR2	0.747	***			
	FINR3	0.742	***			
	SLR1	0.723	***			
	SLR2	0.771	***			
	SLR3	0.765	***			
	FUNR1	0.763	***			
	FUNR2	0.761	***			
	FUNR3	0.815	***			
WTA (Willingness to Adopt)	WTA1	0.770	***	0.906	0.7623	0.871
	WTA2	0.767	***			
	WTA3	0.730	***			

注:***$p < 0.001$.

TABLE 3 Results of discriminant validity analysis.

	SN	PEOU	PU	PR	WTA
SN	0.864				
PEOU	0.608	0.839			
PU	0.653	0.397	0.822		
PR	-0.680	-0.730	-0.621	0.780	
WTA	0.599	0.656	0.582	-0.774	0.867

Note: The diagonal data of the matrix are AVE, square root, and the other are corresponding correlation coefficients.

0.85, indicating good internal consistency. The Average Variance Extracted is greater than 0.5, indicating that the selected dimension can well explain the Variance of variables. At the same time, the square root of the average variance extraction (AVE) of each potential variable is greater than its correlation coefficient with other potential variables, indicating that each potential variable has good discriminant validity. On the whole, the research model has good validity. The data obtained after sorting are shown in Table 2; Table 3:

4.2 Measurement model analysis

4.2.1 Model fit test

CFA was used to measure the fitting degree of the model. Amos26.0 software was used in this study, and Maximum Likelihood was used to test the structural equation model of 617 questionnaire data obtained and the hypothesis model of the influence of social network on villagers' willingness to adopt. To verify the fit of the model. As shown in Table 4, The ratio of chi-square (χ^2) to degree of freedom (df) is 2.671 (χ^2 = 649.02, df = 617), less than The threshold 3, Incremental Fit Index (IFI = 0.972), goodness of Fit Index (GFI = 0.924), incremental Fit Index (IFI = 0.972), goodness of Fit Index (GFI = 0.924) Relative Fit Index (RFI) = 0.941, Comparative fit index (CFI = 0.972) and tacker-Lewis index (TLI = 0.969) are all higher than 0.90. The

TABLE 4 Structural equation model fit index value.

Fitness index	Recommended values	Parameter values
χ2	the smaller the better	649.02
χ2/df	<3	2.067
RMSEA	<0.06	0.042
NFI	>0.9	0.947
CFI	>0.9	0.972
GFI	>0.9	0.924
AGFI	>0.8	0.908
IFI	>0.9	0.972
TLI	>0.9	0.969
RFI	>0.9	0.941

root mean-square Error of approximation (RMSEA = 0.042) is less than 0.08. The good effect of these indicators indicates that the measurement model in this paper has a good fitting degree.

4.2.2 Structural equation model analysis

In this paper, the sampling mode with the put back is adopted. By setting the sample size of Bootstrap to 5,000 and the confidence level to 95% in Amos26.0 software, Bootstrap ML operation analysis is conducted to test the structural relations and standardized path coefficients among potential variables. The specific results are shown in Table 5. The results showed that all the hypotheses passed the test, and the normalized path coefficients were significant at $p < 0.001$. At the same time, after bollen-stine Bootstrap operation analysis of this model, the p value is 0.000 < 0.001, indicating that the null hypothesis model can be accepted, that is, social network plays a positive role in promoting the willingness of villagers to adopt photovoltaic products, and the model with perceived usefulness, perceived ease of use and perceived risk as the intermediary variables is established.

From Table 5, path coefficients of latent variables indicate that social network plays a positive role in promoting villagers' willingness to adopt rooftop PV products, namely **H1** is established. Social network has a positive impact on villagers' perceived ease of use, that is, **H2a** and **H2b** are established. Social network also has a positive influence on villagers' perceived usefulness, that is, **H3a** and **H3b** are established. There is also a positive relationship between perceived ease of use and perceived usefulness based on TAM model, that is, **H4a** is valid. Social network has a negative impact on villagers' perceived risk, **H5a** is true, and perceived risk also has a negative impact on villagers' willingness to adopt rooftop PV products, **H5b** is true. The perceived characteristics of farmers have a negative impact on the perceived risks of farmers. Perceived ease of use and perceived usefulness can reduce perceived risks, so **H6a** and **H7a** are both valid.

4.3 Analysis of multiple mediating effects of perceived characteristics

As for the multiple mediating effect test of structural equation model, Wen and Ye, (2014) believed that if independent variable A can influence dependent variable C through another variable B, then B can be considered as an intermediate variable between the two. If there are multiple mediating variables between independent variable A and dependent variable C, then the chain multiple mediating effect model can be formed. In this case, testing the influence path between the two variables alone cannot effectively reveal the clear relationship between the underlying variables, and the multiple mediating effects of the conduction path of the underlying variables in the model should also be tested. The model established in this paper is relatively complex. There are three chain mediations and parallel mediations, which constitute a multi-mediation model.

Therefore, the test of the mediation effect model in this paper is divided into two steps. First, the mediation effect test method proposed by Baron and Kenny (1986) is used for reference. The

TABLE 5 Results of structural equation model analysis.

Hypothesis	Path	Std.Estimate	S.E.	C.R.	P	Result
H1	SN→WTA	0.133	0.042	3.127	***	Supported
H3a	SN→PU	0.322	0.046	7.303	***	Supported
H2a	SN→PEOU	0.571	0.044	13.03	***	Supported
H5a	SN→PR	−0.192	0.033	−3.609	***	Supported
H4a	PEOU→PU	0.524	0.049	11.218	***	Supported
H6a	PEOU→PR	−0.486	0.042	−9.56	***	Supported
H7a	PU→PR	−0.308	0.039	−5.448	***	Supported
H5b	PR→WTA	−0.574	0.078	−8.444	***	Supported
H3b	PU→WTA	0.094	0.039	3.675	***	Supported
H2b	PEOU→WTA	0.143	0.047	3.498	***	Supported

Note: ***$p < 0.001$.

TABLE 6 Comparison of fitting indexes of multiple models.

Model	Form of construction	χ2/df	RMSEA	NFI	RFI	IFI	TLI	CFI	GFI
Original Model	The multiple mediation model of this paper	2.067	0.042	0.947	0.941	0.972	0.969	0.972	0.924
Competition Model 1	A parallel mediation model with PU, PEOU and PR as mediating variables	3.263	0.061	0.916	0.907	0.94	0.935	0.94	0.877
Competition Model 2	Structural equation model with PU and PEOU as intermediate variables	5.403	0.085	0.948	0.931	0.957	0.943	0.957	0.933
Competition Model 3	Structural equation model with PR as intermediate variable	2.579	0.051	0.948	0.941	0.967	0.963	0.967	0.926
Alternative Model	PU, PEOU and PR directly affect WTA (without mediating effect)	5.673	0.087	0.853	0.839	0.876	0.863	0.875	0.802

multiple mediation models are disassembled, three competing models and one alternative model are set up in turn, and multiple mediation effect models are compared. Thus, the rationality of the multi-intermediary model established in this paper is preliminarily tested. The specific test results are shown in Table 6:

Based on the metrics in Table 6 (χ2/DF, RMESA, NFI, RFI, IFI, TLI, CFI, GFI[8]) and the potential path estimates in Figures 4A–D, The multiple mediation model composed of five latent variables is established and its goodness of fit is the best among the five models. By comparing the original model with competition model 2, it is concluded that social network can affect villagers' willingness to adopt rooftop PV products through perceived usefulness and perceived ease of use, that is, **H4** is established. Compared with competition model 3, it is concluded that a single variable of perceived risk is insufficient to explain the mechanism of social network's influence on villagers' willingness, and the null hypothesis model can further explain the relationship between the two. Therefore, the influence of social network on villagers' willingness to adopt can play a role through villagers' perceived characteristics (perceived usefulness, perceived ease of use) and perceived risk, that is, **H6** and **H7** are established.

However, Baron and Kenny (1986)'s approach has some drawbacks, such as the possibility that the overall effect may not be significant in the presence of inhibitory variables. For example, in the model established in this paper, the impact of villagers' perceived characteristics on villagers' willingness to adopt is positively correlated, while the impact of perceived risk on villagers' willingness to adopt is negatively correlated. A parallel mediation model is established between the two. Therefore, when SN has a positive impact on villagers through PU and PEOU, SN also has a negative influence on villagers' willingness to adopt through PR (inhibitory variable), which may cause the effects of the two to cancel each other and result in insignificant overall effect. At the same time, some studies also pointed out that the causal step method has the lowest test effectiveness and can not effectively find the mediation effect. Secondly, different standard error formulas will also lead to inconsistent test results, while Bootsrap method avoids such problems. In Sobel test, normal distribution hypothesis should be advanced, which is generally not easy to be established. Bootstrap method does not need to carry out distribution hypothesis, so Bootstrap method is one of the most effective test methods.

In this paper, bias correction non-parametric percential Bootstrap method was used to test the mediation effect between each potential variable by using the macro program PROCESS developed by Hayes in SPSS26.0 software. The model number was set as Model 6, the confidence interval was 95%, and the Bootstrap sample size was 5,000. If the Bootstrap 95% confidence interval does not contain 0, it indicates that the mediation effect between latent variables is significant. The specific test results are shown in Table 7:

From Table 7, we found that the mediation effect works through six mediation chains. Firstly, the mediating effect of social network on villagers' willingness to adopt through perceived risk (Ind1) was 0.0995, and the Bootstrap 95% confidence interval was [0.0643, 0.1412], indicating that perceived risk had a significant mediating effect. Second, social network has an effect on adoption intention through perceived ease of use and perceived usefulness (Ind2, 3), which is 0.0763 and 0.0357. The Bootstrap 95% confidence intervals were [0.0472,0.1087] and [0.0173,0.0588], respectively, indicating that the perception characteristics based on TAM model had a significant mediating effect.

Thirdly, the mediating effect of social network on adoption intention through perceived ease of use and perceived risk (Ind4) was 0.0385, and the Bootstrap 95% confidence interval was [0.023,0,0563], indicating that the chain mediation effect with perceived ease of use and perceived risk as mediating variables was significant. Fourth, the mediating effect of social network on adoption intention through perceived usefulness and perceived risk (Ind5) was 0.0159, and the Bootstrap 95% confidence interval was [0.0074,0.0267], indicating that the chain mediating effect with perceived usefulness and perceived

8 These indicators refer to: Root mean-square Error of approximation, Normed fit index, Relative Fit Index, Incremental Fit Index, tacker-Lewis index, Comparative fit index and Goodness of Fit Index

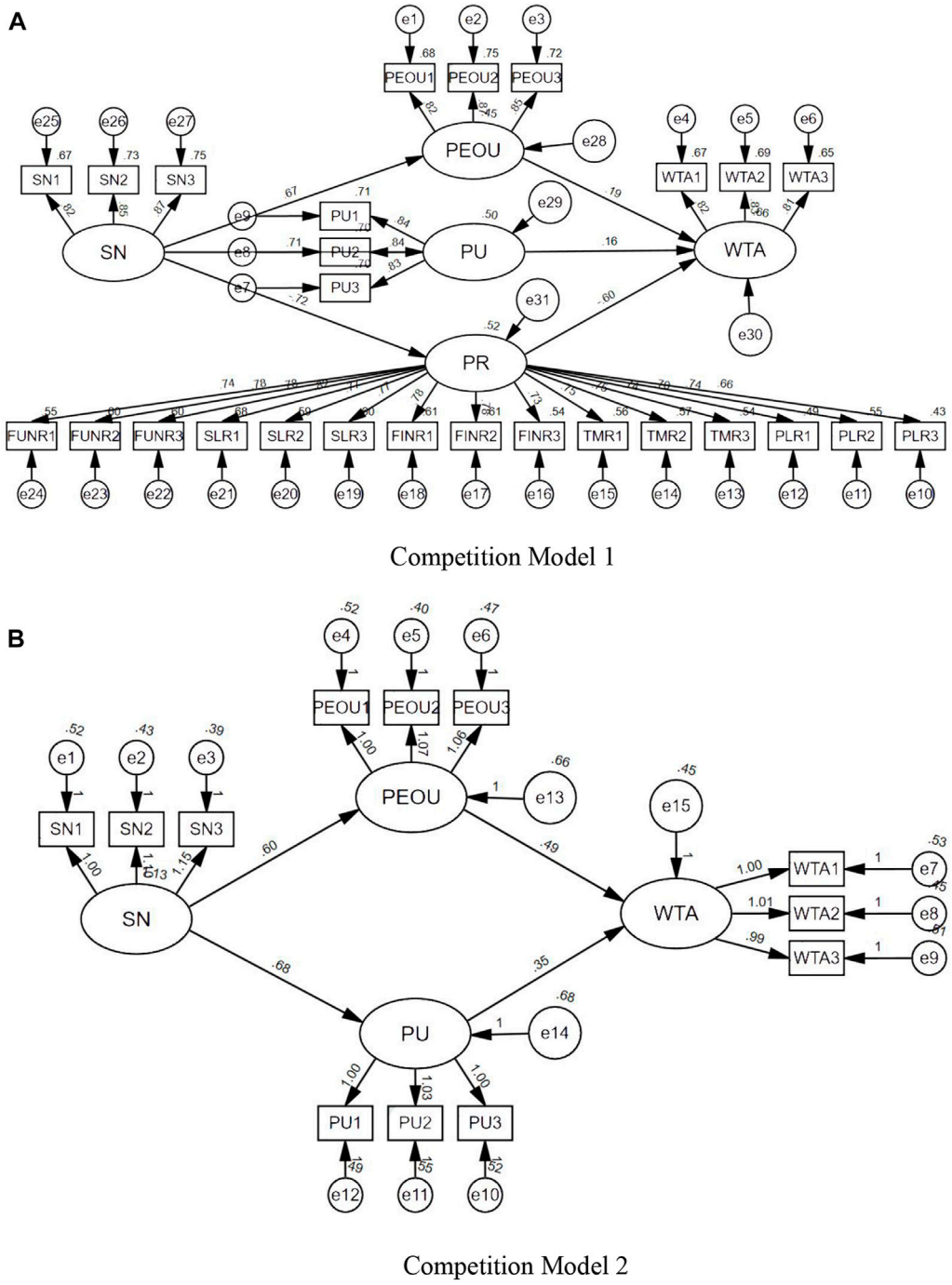

FIGURE 4
Competition model 1–3. Alternative model. **(A–D)** respectively represent four different competition models, corresponding to Table 6.

risk as mediating variables was significant. Fifth, the mediating effect of perceived ease of use and perceived usefulness of social network on adoption intention (Ind6) was 0.0117, and the Bootstrap 95% confidence interval was [0.0048,0.0211], indicating that the chain mediating effect of perceived ease of use and perceived usefulness as mediating variables was significant. Therefore, according to the first and second, it can be concluded that the parallel mediating effect of perceived usefulness, perceived ease of use and perceived risk as the mediating variables is significant, that is, H2,

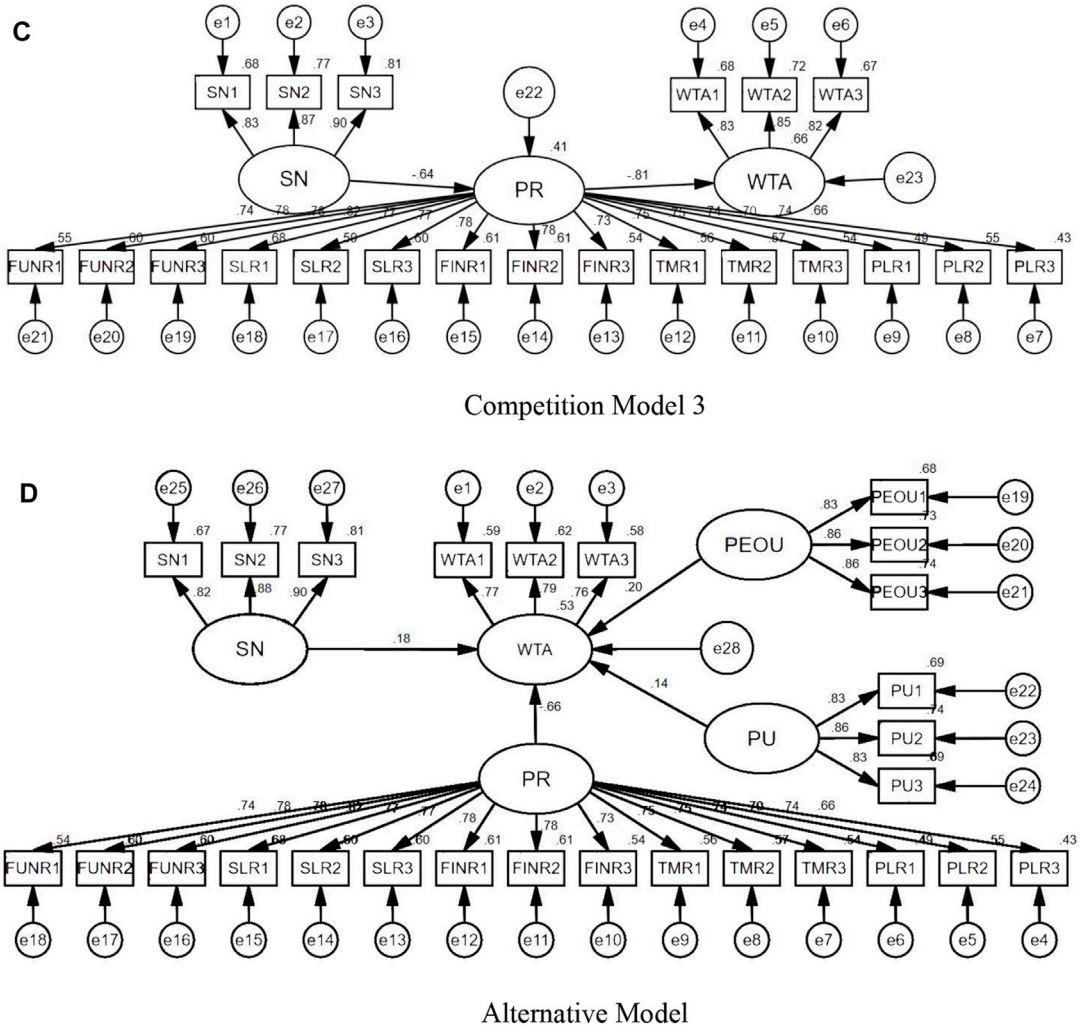

FIGURE 4

TABLE 7 Results of multiple mediating effect.

Path		Estimate	S.E.	Percentile 95%CI		Proportion of effect value (%)
				Lower	Upper	
Ind1	SN→PR→WTA	0.0995	0.0196	0.0643	0.1412	27.60%
Ind2	SN→PEOU→WTA	0.0763	0.0156	0.0472	0.1087	21.17%
Ind3	SN→PU→WTA	0.0357	0.0107	0.0173	0.0588	9.90%
Ind4	SN→PEOU→PR→WTA	0.0385	0.0084	0.023	0.0563	10.68%
Ind5	SN→PU→PR→WTA	0.0159	0.0049	0.0074	0.0267	4.41%
Ind6	SN→PEOU→PU→WTA	0.0117	0.0042	0.0048	0.0211	3.25%
Total effect	0.2776	-	77.00			

H3 and H5 are assumed to be valid. According to the third, fourth and fifth, it can be concluded that the chain mediation effect established in the model is significant, that is, H4, H6 and H7 are established.

5 Conclusion and policy implications

5.1 Conclusion

From the perspective of social capital, this paper explored the influencing factors of Chinese rural residents' willingness to adopt rooftop PV products. After determining the important role of social network, the multiple mediating effects of the three latent variables of perceived usefulness, perceived ease of use and perceived risk in TAM were studied. The main conclusions are as follows:

(1) Social network is an important factor to enhance villagers' willingness to adopt residential rooftop PV products. The effect is mainly reflected in four dimensions, namely, "attitudes of relatives and neighbors", "demonstration effect", "Online learning and interaction", and "policy support". First of all, the important influence of rural social networks is reflected in the attitudes of relatives and neighbors. As a settlement village, the attitude of villagers' neighbors greatly affects their psychological consciousness and leads them to initially have the idea of adopting rooftop photovoltaic products. When they perceive strong support from relatives and neighbors, the feasibility of installation will increase, and then the willingness of villagers to adopt them will be enhanced. Secondly, the surrounding successful cases will greatly enhance villagers' confidence in the feasibility of photovoltaic installation, so as to stimulate their willingness to adopt. In addition, when villagers perceive strong national or local support policies, their willingness to adopt will be further enhanced. Finally, the social network level of rural communities will greatly help villagers to learn the operation of photovoltaic power generation, thus reducing many concerns of villagers, and their willingness to adopt will also be greatly improved. In general, the richer the social network resources available to villagers, the stronger their willingness to use them.
(2) Perceived usefulness and perceived ease of use have a significant positive impact on villagers' willingness to adopt rooftop PV products, and perceived risk has a significant negative impact on villagers' willingness. In addition, the three have parallel mediating effects in the path of social network influencing intention. The perception level of villagers has a direct and significant impact on the willingness to adopt. However, the discussion and communication between groups become an important source of effective information, and the acquisition of such information promotes the villagers' willingness to adopt because of the relatively closed environment in rural areas and the low level of education of farmers. At the same time, compared with the positive perception of products, the negative risk perception is an important factor that reduces villagers' willingness, and the perceived risk plays the most mediating effect.
(3) The mediating effect of "social network -- perceived ease of use -- perceived risk -- willingness" was the largest. This chain shows that villagers' social network can effectively improve villagers' perceived ease of use by virtue of its unique network mutual assistance and learning functions, thus reducing villagers' risk perception and enhancing their willingness to adopt. In fact, the degree of perceived ease of use is related to the time and psychological dimension of perceived risk. The simplicity of operation can not only greatly reduce the time for villagers to learn and master, but also further eliminate various concerns in their hearts. The "social network - perceived ease of use - perceived usefulness - willingness" chain further indicates that photovoltaic enterprises should focus on the easy use and quick installation of photovoltaic products. The chain of "social network - perceived usefulness - perceived risk - willingness" shows that villagers perceive the usefulness of photovoltaic products by obtaining information from social network. On this basis, the villagers' understanding of the function of photovoltaic power generation and the guarantee of photovoltaic loans will be improved, so as to reduce the villagers' perception of functional, financial and social risks.

The conclusions of this paper have rich and important policy implications. Promoting rural renewable energy technology adoption through embedded social network mobilization policies will not only help achieve the goal of rural clean energy transition in China, but also provide reference for other developing countries to promote clean energy technology and achieve sustainable development.

(1) The local government should focus on rural social network, increase policy support for photovoltaic products, encourage local village cadres to take the lead in adopting, play a demonstration role, and give full play to the function of the village committee, actively create an environment conducive to villagers' learning and communication, and advocate a harmonious neighborhood rural atmosphere. At the same time, the government should strengthen the supervision of photovoltaic enterprises and financial institutions, put an end to "photovoltaic loan scam", and protect the rights and interests of villagers.
(2) It is necessary for financial institutions to strengthen the publicity of photovoltaic products and practice the concept of inclusive finance. On the one hand, we should combine the national electricity price subsidy policy to explain the preferential measures of photovoltaic loan in rural areas, and take guidance and encouragement and other relevant

measures to let rural residents realize the preference of rooftop photovoltaic products. On the other hand, it is necessary to improve the villagers' ability to correctly evaluate rooftop pv products, improve the cognitive defects caused by information asymmetry, so as to effectively reduce their financial risk and psychological risk perception, and promote the generation of willingness to adopt.

(3) Rooftop PV enterprises must strengthen the trust between villagers, and constantly improve rooftop PV technology to adapt to the rural market. Photovoltaic enterprises should establish close ties with rural areas and arrange technicians to act as Bridges between enterprises and villagers. The neighborhood structure is used for decentralized guidance, and the rural learning network is constructed to enhance mutual trust, so as to strengthen the contact with villagers, eliminate all kinds of concerns of villagers, reduce their perception of time and psychological risk, and finally improve the willingness of villagers to accept photovoltaic. In addition, enterprises should further develop photovoltaic technology suitable for the use and operation of rural households, take product quality as the core, and break technical bottlenecks to increase product power generation while ensuring service life, so as to improve the positive perception characteristics of villagers, reduce perceived risks of villagers, and improve product demand.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material further inquiries can be directed to the corresponding authors.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national egislation and the institutional requirements.

Author contributions

WW: Writing—original draft, Funding acquisition, Project administration. XG: Writing review and editing Supervision, Conceptualization, Investigation. SJ: Conceptualization, Methodology, Software. XW: Data curation, Investigation, Methodology. XQ: Data curation, Investigation. NL: Funding acquisition, Formal analysis. GZ: Investigation, Data curation. DL: Data curation.

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Conflict of interest

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

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fenvs.2022.999006/full#supplementary-material

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