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Toward Sustainable Energy Consumption: Identifying Barriers to Household Adoption of Photovoltaic Solar Technology

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Received: 08-13-2025 **Revised:** 09-19-2025 **Accepted:** 11-07-2025

Citation: Vu, T. D., Vu, P. T., Nguyen, H. N., & Nguyen, T. H. (2025). Toward sustainable energy consumption: Identifying barriers to household adoption of photovoltaic solar technology. *Chall. Sustain.*, *13*(4), 571–586. https://doi.org/10.56578/cis130408.

Abstract: The key target of developing renewable energy systems is critical for countries to combat the impact of climate change and bolster energy security. Among the many available green powers, solar energy generation has been developed worldwide. The exponential acceleration of this technology has stimulated household customers in particular, to switch from the role of consumers to suppliers by selling electricity generated from their home panels. It is anticipated that this change would form a new business model for electricity sales and promote a sustainable energy supply chain, yet the change is still confined to a certain extent in developing markets. In this light, this study identified and evaluated the impact of seven barriers on the household intention to adopt photovoltaic (PV) solar systems. The results of the structural equation modeling (SEM) analysis, based on the data from 288 households in Vietnam, revealed that six barriers, namely uncertain government policies, financial barriers, brand trust barriers, product knowledge barriers, location-based barriers and technical barriers had significant negative impacts on PV adoption intention, while the hypothesized influence of environmental knowledge barriers on this intention was insignificant. Among the validated barriers, uncertain government policies and financial barriers were the most critical factors hindering the household intention to adopt PV solar systems. Notably, while rural surveyed households had the higher means in adoption intentions, technical barriers and financial barriers, their results in location-based barriers and brand trust barriers were lower than the urban ones. Theoretically, this study contributed to expansion of pro-environmental behavior theory and barriers to adoption intention of household consumers. Besides, the findings of this study suggested policy makers, enterprises and technology providers how to promote household adoption thanks to the raised awareness of which barriers are concerned in Vietnam market.

Keywords: Renewable energy; Photovoltaic solar systems; Uncertain government policies; Householders' perspective; Sustainable development; Vietnam

1. Introduction

Compared to the end of the 19th century, the global temperature has increased by more than 1.18°C, leading to adverse effects on the global environment, such as melting ice and rising sea levels. Thus, reducing CO_2 emissions is considered a responsibility of all countries globally (Yuan et al., 2022). At present, fossil fuels are still the common fuels that generate 80% of global energy and 66% of electricity; yet being the cause of approximately 60% of greenhouse gases, they destroy the environment extensively. To deal with the crisis urgently, communities could replace fossil fuels and switch to renewable energy sources by breaking down technological, financial, and political barriers (United Nations Environment Programme, 2024). In recent decades, renewable energy technologies have been posed as a solution to protect the environment and promote the circular economy. Developing a renewable energy supply chain assists in improving the energy resilience of the supply chain and the viability of the circular business ecosystem (Luthra et al., 2022).

As an emerging economy in Southeast Asia, Vietnam has a population of nearly 100 million people and possesses many favorable natural conditions for developing renewable energy such as hydropower, wind power, solar power, geothermal and biofuels (Social Republic of Vietnam Government News, 2022a). To serve the production needs of the economy and the demand from households, the Government of Vietnam has put great efforts to build a renewable supply chain, a long-term strategy for 2030. The vision 2050 progresses towards the goal of increasing the renewable energy supply chain, especially solar and wind power (Social Republic of Vietnam Government News, 2022b). In 2019, the introduction of a new solar policy, Feed-in Tariff (FiT), appealed to consumers and micro investors with special terms (Prime Minister of Vietnam, 2020). To be more specific, FiT allows PV solar system owners to sell excess electricity to Vietnam Electricity Corporation (EVN), the monopoly of electricity retailing in Vietnam, and the mechanism is illustrated in Figure 1. Given the planned subsidiaries from the government to EVN to promote this policy, households as micro suppliers to EVN, can sell at a promising rate of US$93.5/MWh for 20 years. This price is relatively high when compared to other Asia Pacific countries (Vu et al., 2023), regardless of certain tax exemptions (Do et al., 2020). By 2020, Vietnam had already achieved the most installed solar capacity in South East Asia and ranked top 10 globally for the same category (Do et al., 2021; Social Republic of Vietnam Government News, 2022c).

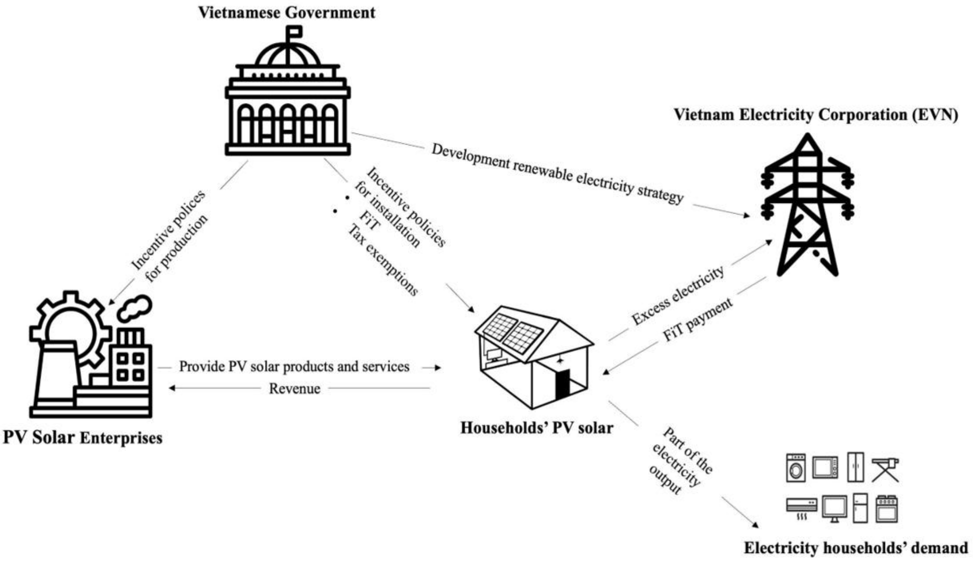

Figure 1. Operation of PV solar system in Vietnam

Studies on the intention of renewable energy adoption are widely recognized as part of the broader field of pro-environmental behavior research (Ghosh & Prasad, 2024). Understanding this variable is essential for identifying strategies to promote environmentally responsible consumption and guide the marketing of eco-friendly products (Legault et al., 2024). Despite growing scholarly interest, existing theories of pro-environmental behavior continue to exhibit limitations. A key recommendation in recent literature is to expand the theoretical framework by placing greater emphasis on barriers to adoption (Hasan & Ghosh, 2024; Takács-Sánta, 2007). Notably, deficiencies in environmental knowledge, socio-psychological characteristics, market conditions, and policy frameworks have been identified across multiple studies. These barriers merit deeper investigation, as they could inform practical solutions for overcoming challenges to sustainable behavior (Fu et al., 2020; Quimby & Angelique, 2011; Wynveen et al., 2015). Accordingly, research that explores these constraints holds significant potential to contribute both theoretically and practically to the advancement of pro-environmental behavior scholarship.

Although numerous studies have sought to explain household adoption of photovoltaic (PV) solar systems through various analytical approaches (Kesari et al., 2018; Sun et al., 2018; Vu et al., 2023), much of the existing literature emphasized motivational determinants such as personal traits, psychological factors, consumption habits, and government incentives. However, the explanatory power of these models remains limited (Jirakiattikul et al., 2021; Li et al., 2022; Nguyen et al., 2022; Sun et al., 2018; Vu et al., 2023). At the same time, research addressing barriers to PV solar development has primarily adopted qualitative methodologies, often lacking systematic impact assessments (Do et al., 2020; Lo et al., 2018; Painuly, 2001).

This study was designed to identify significant barriers and quantitatively assess their influence on the intention of household PV solar adoption, in response to the gap found in the expansion of the theoretical framework of pro-environmental behavior (Hasan & Ghosh, 2024; Takács-Sánta, 2007) within the context of developing economies such as Vietnam. Through empirical analysis, the research aims to provide more robust and compelling evidence on the issue. Furthermore, it investigates perceptual differences between rural and urban households, thus generating meaningful implications for stakeholders to promote the development of renewable energy infrastructure in Vietnam.

2. Literature Review and Development of Hypotheses

2.1 Pro-Environmental Behavior

Scholars have employed various terms to characterize environmentally beneficial actions, including environmentally concerned, responsible, and significant acts, as well as pro-environmental behavior (Lee et al., 2013). Pro-environmental behavior refers to deliberate actions undertaken by individuals to mitigate negative environmental impacts and enhance environmental quality (Vu et al., 2025). According to Homburg & Stolberg (2006), such behaviors spanned from environmental activism (e.g., participation in environmental organizations), non-activist public-sphere efforts (e.g., petitioning for environmental causes), private-sphere practices (e.g., conserving energy and purchasing recycled goods), and workplace behaviors (e.g., sustainable product design). Otto et al. (2021) conceptualized pro-environmental behavior as a subset of prosocial behaviors intended to promote the well-being of others or the broader society. Caprara & Steca (2007) further argued that prosocial actions were enabled by individuals perceived self-efficacy and capacities of emotional regulation.

Pro-environmental behavior is influenced by a diverse array of enablers and barriers (Gkargkavouzi et al., 2019; Gómez-Olmedo et al., 2021; Novacka et al., 2019). Prior research has identified several key determinants, including individual capability, economic conditions, environmental knowledge, contextual factors, and product/service characteristics (Chen & Deng, 2016; Ling & Xu, 2020; Novacka et al., 2019; Vu et al., 2025). This study, situated within the context of household adoption of PV solar systems, examined barriers across three dimensions: (1) individual capability, specifically environmental knowledge and financial constraints; (2) product-related barriers, namely product knowledge and brand trust; and (3) contextual barriers, comprising policy uncertainty, location-based limitations, and technical challenges. These factors were integrated into a conceptual framework to evaluate their impact on household intention to adopt PV solar technologies.

2.2 Adoption Intention

Intention, which plays a role in motivating individuals' usage behavior (Davis, 1989), is an essential factor in many theoretical behavior models. According to Ajzen (1991), intention was a psychological state that set factors motivating an individual to make decisions, his or her determination, and level of effort to perform the behavior. Intention of PV solar adoption has been the subject of studies in many countries to assess the potential for developing renewable energy systems (Li et al., 2022). Nguyen et al. (2022) emphasized that the intention of PV solar adoption was influenced by many factors of individual characteristics, social influences, and government incentive policies. Promoting the intention of PV solar adoption requires the coordination and active participation of many stakeholders involving the government and PV providers; it also depends on the knowledge, awareness, and innovativeness of consumers (Vu et al., 2023).

2.3 Financial Barriers

Financial barriers are related to product prices, capital accessibility, and operating costs; they pose significant challenges to the development of renewable energy supply chain in emerging markets (Karatayev et al., 2016; Mirza et al., 2009; Painuly, 2001). Especially in the early stage when accessories of a PV system and skilled technicians are widely available, initial investments in installation and maintenance costs are often high (Luthra et al., 2015)., Limited access to financial support like loan, together with pricey expenses, impedes the development of solar energy supply chain (Painuly, 2001; Reddy & Painuly, 2004).

Several empirical evidence emphasized that monetary barriers could constrain pro-environmental consumption (Nguyen et al., 2019). In Vietnam, the initial investment in the installation of PV solar systems is high relative to the average income of households. For example, the cost of installing a system of seven 450Wp panels with a capacity of 3 kWp ranges from VND 40,000,000–48,000,000, which is equivalent to approximately ten times of the Vietnamese monthly average income (GSO, 2023). According to the definition of financial barriers above, this comparison leaves no concrete implication on the obstacles posed by money-related issues and the intention of households to use PV panels. Reddy & Painuly (2004), through descriptive statistics and weighted average ratings, identified the financial barriers which critically hindered the adoption of renewable energy in India. Similarly, Rawea & Urooj (2018) also stated that financial barriers could strongly affect the success of renewable energy development projects in Yemen. From the above arguments, a hypothesis has been formulated:

H1: Financial barriers negatively affect the intention of PV solar system adoption among the households in Vietnam.

2.4 Environmental Knowledge Barriers

Environmental knowledge means knowing and understanding facts, concepts, and relationships concerning the subject-related environment (Nguyen et al., 2025; Smith & Paladino, 2010). Joshi & Rahman (2015), in a study synthesizing analysis from 53 articles, identified the lack of environmental knowledge as an essential barrier for each individual to move towards pro-environmental behaviors. Meanwhile, many empirical studies have shown that the promotion of environmental knowledge could affect the attitude and behavior of using environmentally friendly products (Foroughi et al., 2022; Nguyen et al., 2019). However, several scholars found no linkage between these two factors in many studies on sustainable consumption, especially in emerging markets such as Malaysia, Korea, and China (Chekima et al., 2016; Jiang & Kim, 2015). Kesari et al. (2018) demonstrated that environmental knowledge could enhance the intention of adopting PV solar products in the Indian market. Though under the perception of environmental knowledge as a barrier, there have been few studies that establish related scales to assess the impact. From the above discussions, another hypothesis has been proposed:

H2: Environmental knowledge barriers negatively affect the intention of PV solar system adoption among the households in Vietnam.

2.5 Product Knowledge Barriers

Product knowledge is defined as consumer perception of specific information about a product and can be subdivided into subjective and objective knowledge (Brucks, 1985; Rao & Monroe, 1988). Many studies showed that individuals with high product knowledge were more likely to buy and use products (Burton et al., 2009; Lee & Lee, 2009). In contrast, a lack of product knowledge hinders customers' decision to use products in many different research contexts (Connell, 2010; Joshi & Rahman, 2015). In addition, some studies discovered that for new products appearing on the market for a short time, problems with product information and label recognition could cause difficulties for consumers when purchasing a green product (Nguyen et al., 2019). Huang & Cheng (2022) showed the possibility of enhancing the relationship between the attitude of solar energy adoption and product knowledge of PV solar installation in Taiwan. However, there are limited studies empirically examining the lack of knowledge as a barrier to PV solar products in the Vietnamese market. Hypothesis H3 was formed below:

H3: Product knowledge barriers negatively affect the intention of PV solar system adoption among the households in Vietnam.

2.6 Brand Trust Barriers

Brand trust has been defined as a customer's commitment to a brand based on the expectations of its perceived benefits (Lau & Lee, 1999). Brand trust refers to the reliability, the level of expectation, the ability to guarantee satisfaction when choosing, and the assurance of commitments from the business (Chen, 2010; Delgado-Ballester, 2004). Several studies have concluded that enhancing brand trust could promote the purchasing intention of customers (Husain et al., 2022; Punyatoya, 2014). Strupeit & Palm (2016) stated that it was necessary to improve customer trust towards product suppliers to promote the development of PV solar systems. In the emerging markets, many things could still be improved in managing brands in the market. Nguyen et al. (2022) proved that brand trust did not predict customers' intention of PV solar installation. In Vietnam, the activities of equipment production for PV solar systems are still limited. For example, 99% of solar cells assembled in Vietnam are imported and mainly purchased from China. In 2019, enterprises in Vietnam imported 36.2 million solar panels with a value of 844.8 million USD (an increase of more than 224%) compared to 2018. In 2020, the import volume tripled to 114.6 million solar panels with a value of up to 2.4 billion USD (an increase of more than 185%) compared to 2019. There are seven to eight large solar panel factories in the country, but only one business is from Vietnam (SolarBK, 2021). In this situation, more information is required by customers to trust panel suppliers in the market (Nguyen et al., 2022). From the above analysis, a lack of brand trust can negatively affect the intention of adoption by customers. Hypothesis, H4, was proposed:

H4: Brand trust barriers negatively affect the intention of PV solar system adoption.

2.7 Barriers of Uncertain Government Policies

In order to overcome the barriers and encourage residents to adopt new technologies, such as PV solar, to protect the environment, support from the government is essential (Nguyen et al., 2022). Through fiscal, tax and installation policies, the government could enhance the attitude and adoption intention of households (Huang & Cheng, 2022; Nguyen et al., 2022). In many countries, governments buy excess electricity from households with PV solar systems at a preferential price, to help increase the financial benefits for participants (Byrnes et al., 2013; Huang & Cheng, 2022). The limitation of resources, when implementing the strategy of renewable energy development, led to conflicts among stakeholders in several countries (Lo et al., 2018). Similarly, Vu et al. (2023) indicated that financial matters arising from FiT incentives policy was the cause to reduce the effectiveness of such policies for residents to adopt PV solar in emerging markets. Furthermore, uncertain government policies such as frequent changes and revisions of solar policy, un-supportive policies, lack of commercial agreements and technical guidelines, and lack of uniformity in statutory approvals were recognized as barriers to developing PV solar networks (Lo et al., 2018; Rathore & Panwar, 2022; Sirin & Sevindik, 2021). Despite having a limited number of studies, empirical evidence would be indispensable for evaluating the influence of these barriers on the intention of adopting PV solar in households. From the above arguments, the hypothesis was proposed:

H5: Barriers of uncertain government policies negatively affect the intention of PV solar system adoption.

2.8 Technical Barriers

Technical barriers to PV solar adoption involve concerns related to product quality, operations and maintenance, or technical difficulties in use (Kabir et al., 2018). Several scholars assessed technical barriers, including product quality, lack of standards, codes and certification, lack of entrepreneurs, and system constraints (Painuly, 2001). In their study of India, Dhingra et al. (2023) referred to technical barriers such as voltage fluctuations and lack of maintenance services to support households during the operation of PV solar systems. In emerging economies like Vietnam, PV solar technology has not been on the market for a long time. As customers' knowledge and the supporting industry for this product are still limited, technical barriers occur when customers consider installing PV solar. Do et al. (2020) pointed out some significant challenges related to technical barriers during the development of PV solar systems in Vietnam; for instance, transmission infrastructure, overload of transmission grids, and troubles from site clearance activities. Technical barriers are widely recognized when developing solar energy supply chain; however, most studies approached the problem via descriptive analysis or discussion about government policies. There have not been enough studies evaluating the impact of this barrier on residents' adoption intention, especially in Vietnam. Hypothesis H6 was proposed:

H6: Technical barriers negatively affect the intention of PV solar system adoption among the households in Vietnam.

2.9 Location-Based Barriers

Location-based barriers are resulted from the adverse conditions at the installation venues of PV solar systems, such as lack of sunshine, insufficient installation space, and natural conditions hindering the efficiency of the system. To install PV solar systems, households should have enough space to install panels, provided that the panels are exposed to a large amount of sunshine for the system to operate at the correct capacity. Usually, the ideal installation location will be on the roof, where it can obtain the most sunlight. For example, in Vietnam, 7 panels are needed for a 3kW power system in an area of 18m^2 and for a capacity of 5kW, 12 panels and a space of 30m^2 are required (Intech Energy, 2023). Apart from space issues and the lack of sunshine, buildings that do not support PV solar are considered to be barriers in densely populated urban areas (Lo et al., 2018). In addition, location-based barriers such as "dust formation" could affect the performance of PV solar (Dhingra et al., 2023; Hachicha et al., 2019). Thus, these barriers may concern residents when installing PV solar systems. Hypothesis H7 has been proposed:

H7: Location-based barriers negatively affect the intention of PV solar system adoption among the households in Vietnam.

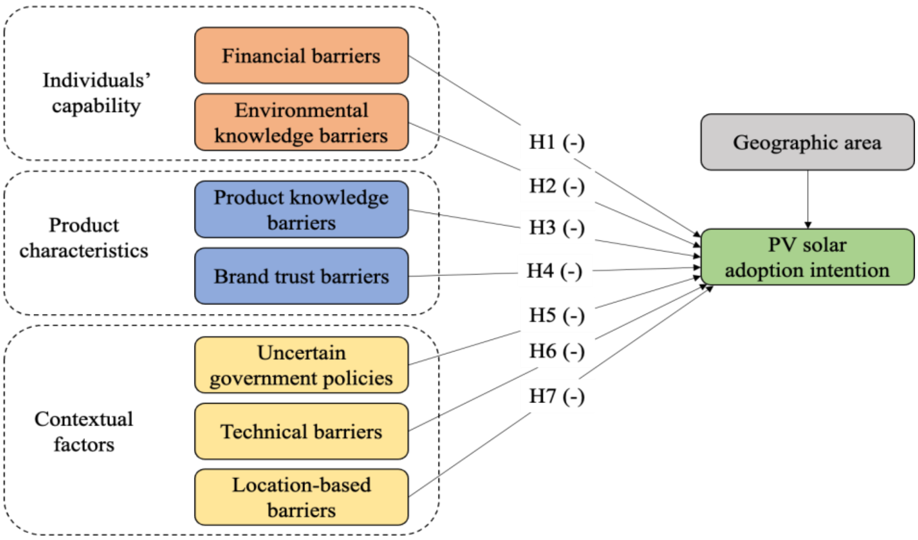

Figure 2. Research model

From the section above, a research model was proposed to investigate the impact of seven barriers on the intention of households to adopt PV solar systems in Vietnam. The research model is described in Figure 2.

3. Methodology

3.1 Research Design

This study applied interviews and a quantitative method to accomplish the objectives. Firstly, a measurement scale was established via adaption from related studies. Afterwards, in-depth interviews were conducted with five experts and fifteen householders to develop a measurement scale and guarantee that all statements suited the Vietnam context (Harkness et al., 2004). In order to test reliability, convergent validity, and discriminant validity, this study used two software applications, SPSS 26 and AMOS 26, to conduct Common Method Variance test, Exploratory Factor Analysis (EFA), Cronbach Alpha (α) test, and Confirmatory Factor Analysis (CFA). The hypotheses were tested by Covariance-Based Structural Equation Modeling (CB-SEM) method. The independent sample T-test assessed the differences between the two sample groups. The thresholds to evaluate the suitable level of the model, such as Goodness of Fit Index (GFI), Comparative Fit Index (CFI), Tucker–Lewis's Index (TLI), and Root Mean Square Error of Approximation (RMSEA), were referenced from Hair et al. (2013).

3.2 Measures

The measures in this study were established via references from previous studies and developed from interviews. In addition to the financial barriers, location-based barriers, uncertain government policies and technical barriers adapted from previous studies, barrier scales such as environmental knowledge barriers, brand trust barriers, and product knowledge barriers were developed from the motivational scale.

Two language experts were invited to translate statements from English to Vietnamese and vice versa. Next, a cross-check was performed to ensure the consistency of the translated content. Afterwards, in-depth interviews were performed with five experts, i.e., two PhD in Marketing, two managers from solar product enterprises, and one policy-maker in the electric industry (Harkness et al., 2004). Next, focus group interviews were carried out with fifteen households. Several amendments were made to fix misunderstandings and unclarity errors. Each statement describing every single item was measured on a 7-point Likert scale ranging from 1-Strongly disagree to 7-Strongly agree. From the proposed items, a pilot test was used to check the reliability of the instruments with 40 respondents. The test results of Cronbach Alpha value are higher than 0.7, so reliability was guaranteed in this stage.

After the above process, three items of adoption intention were adapted from Nguyen et al. (2022). Financial barriers include four items adopted from Luthra et al. (2015), Painuly (2001), and Tanner & Wölfing Kast (2003). Location-based barriers consist of six items adapted from Dhingra et al. (2023) and Lo et al. (2018). Among the seven items in uncertain government policies, three were adapted from Rathore & Panwar (2022) and Sirin & Sevindik (2021). Four items including "*Lack of standard announcement for PV solar product quality from Government*", "*Lack of implementation guidelines from Government*", *"The payment policy is not consistent"* and *"Decentralization policy for stakeholders is not consistent"* were suggested based on the interview results. Environmental knowledge barriers contain five items adopted from Mostafa (2007); product knowledge barriers also have five items adapted from Gleim et al. (2013) and Lin & Chen (2006). Six items were adopted from Chen (2010) and Delgado-Ballester (2004) to measure brand trust barriers. Finally, technical barriers consist of five items adapted from Do et al. (2020) and Painuly (2001).

3.3 Survey Administration and Characteristics of the Sample

Primary data was collected from householders interested in PV solar products in the rural and urban areas in Vietnam. In order to ensure that the respondents have enough knowledge about the research topic, several general questions about renewable energy and PV solar products were asked at the beginning of the survey. The face-to-face interview method was applied to collect information from householders. The selected surveyed provinces and cities need to have good potential for solar power development in Vietnam to ensure the significance of the study. Informed consent was obtained from all subjects involved in the study. Several documents about renewable energy and PV solar products were distributed to householders after having finished the interviews to increase the enthusiasm of respondents.

After two months, 288 responses from householders were received, and the characteristics of this sample were reported in Table 1. Of these, 151 households were from urban areas whereas 137 were from rural households. The gender of householders was predominantly male (81.94%), and the typical age ranges were 26–35 (38.54%) and 36–45 (37.5%). The most common education levels are Undergraduate degrees (56.94%) and Postgraduate degrees (30.9%). Notably, the monthly incomes of households were mainly in the range of 20,000,000–30,000,000 VND

(32.99%) and 30,000,000–40,000,000 (28.82%).

Table 1. Characteristics of the sample

Criterion		Frequency	Percentage (%)
Gender of householder	Male	236	81.94
	Female	52	18.06
Age	18–25	32	11.11
	26–35	111	38.54
	36–45	108	37.50
	Above 45	37	12.85
Education level	High school or lower	2	0.69
	Vocational diploma	9	3.13
	College diploma	24	8.34
	Undergraduate degree	164	56.94
	Postgraduate degree	89	30.90
Monthly household income	< 10,000,000 VND	2	0.69
	10,000,000 VND–20,000,000 VND	54	18.75
	20,000,000 VND–30,000,000 VND	95	32.99
	30,000,000 VND–40,000,000 VND	83	28.82
	Above 40,000,000 VND	54	18.75
Geographic area	Urban	151	52.43
	Rural	137	47.57

4. Results

4.1 Common Method Variance

Several recommendations from Podsakoff et al. (2003) were applied in this study to prevent Common Method Variance errors, such as the information of respondents' personal insurance, and to avoid changes in the order of the survey questions to reduce awareness about the construct of the research model. Finally, Harman's single factor was performed to evaluate the occurrence of Common Method Variance. The results indicated that the single factor only explained 26.887% (< 50%) of the total variance. Thus, Common Method Variance did not emerge in this study (Malhotra et al., 2006).

4.2. Reliability and Validity

Cronbach Alpha test was conducted to assess the reliability of variables, and the results indicated that all α values were more significant than 0.7 and less than 0.95. Detailed results are described in Table 2.

Table 2. Reliability, convergent and discriminant validity

Properties of Items	Factor Loadings (FLs)	Composite Reliability (CR)	Average Variance Extracted (AVE)	Maximum Shared Variance (MSV)
Adoption intention (INT) - α = 0.885				
I have a plan to install PV solar energy	0.861	0.889	0.728	0.393
I intend to install PV solar energy	0.789			
I expect to install PV solar energy in the future	0.906			
Financial barriers (FI) - α = 0.855				
High product price	0.790	0.856	0.598	0.339
High cost of capital	0.721			
High implementation/adaptation costs	0.791			
Limited access to financial support	0.789			
Location-based barriers (LB) - α = 0.894				
Not enough space to install PV solar	0.676	0.904	0.612	0.216
Not enough space for PV solar system to operate with high efficiency	0.724			
Insufficient amount of sunshine/unpredictable weather	0.767			
Building cannot support PV solar installation	0.730			
Weather may not support PV solar products to operate at maximum capacity	0.861			
Dust formation	0.911			

Barriers of uncertain government policies (UGP) - α = 0.879				
Frequent changes and revisions of solar policy	0.681			
Lack of commercial agreements and technical guidelines	0.775			
Lack of uniformity in statutory approvals	0.774			
Lack of standard announcement for PV solar product quality from Government	0.781	0.881	0.516	0.355
Lack of implementation guidelines from Government	0.628			
Payment policy is not consistent	0.694			
Decentralization policy for stakeholders is not consistent	0.680			
Environmental knowledge barriers (EK) - α = 0.916				
Lack of knowledge about benefits brought by PV solar products to the environment	0.807			
Lack of knowledge about the environment issues	0.793	0.918	0.691	0.042
I have a hard time identifying eco-friendly products	0.829			
Lack of knowledge about recycling	0.826			
Choosing eco-friendly products is not my priority	0.897			
Product knowledge barriers (PK) - α = 0.925				
Lack of knowledge about PV solar products	0.834			
Lack of knowledge about PV solar installation	0.894			
Compared to others, my knowledge of PV solar product is limited	0.874	0.926	0.757	0.393
Lack of knowledge about the benefits of PV solar products for the environment	0.877			
Brand trust barriers (BT) - α = 0.939				
Brands of PV solar products on the market are not reliable	0.866			
Brands of PV solar products on the market did not meet expectations	0.817			
Environmental argument concerning a brand is generally not trustworthy	0.839	0.941	0.728	0.206
Brands do not make me feel secure when choosing PV solar	0.825			
The brand does not keep its commitments and promises for environmental protection	0.855			
The brand name does not guarantee satisfaction	0.913			
Technical barriers (TE) - α = 0.935				
System constraints	0.862			
Lack of skilled personnel/training	0.884			
Lack of operation and maintenance facilities	0.799	0.936	0.747	0.076
Lack of entrepreneurs	0.833			
Lack of standard, codes, product quality, and product certification	0.936			

Table 3. Descriptive and correlation analysis

	Mean	SD	PK	BT	UGP	EK	LB	TE	FI	INT
PK	4.488	0.920	**0.870**							
BT	4.772	0.968	0.387	**0.853**						
UGP	5.625	0.673	0.489	0.287	**0.718**					
EK	4.100	0.787	0.155	0.029	0.205	**0.831**				
LB	4.620	0.693	0.380	0.279	0.415	0.171	**0.782**			
TE	4.053	1.162	0.150	0.123	0.199	0.075	0.244	**0.864**		
FI	4.471	0.679	0.582	0.288	0.268	0.125	0.178	0.075	**0.773**	
INT	3.256	0.703	-0.627	-0.454	-0.596	-0.180	-0.465	-0.275	-0.534	**0.853**

Note: Diagonal values are highlighted to indicate the square root of the AVE of the construct; SD: Standard Deviation

In order to evaluate convergent and discriminant validity, CFA was conducted. Model fit indices such as χ^2 = 1.337 (< 3); *p*-value = .000 (< 0.05); GFI = 0.866 (> 0.8); TLI = 0.967 (> 0.9); CFI = 0.970 (> 0.9); RMSEA = 0.034 (< 0.08) satisfied thresholds suggested by Hair et al. (2013) and Bagozzi & Yi (1988). In this study, the Average Variance Extracted (AVE) of all variables were greater than 0.5 (ranging from 0.516 to 0.757) and Composite Reliability values were more than 0.7 (ranging from 0.857 to 0.941). Thus, convergent and discriminant validity were guaranteed to meet the thresholds of Hair et al. (2013). Besides, the square root of the AVE of the construct was greater than the correlation values of groups of variables, and all Maximum Shared Variance was smaller than the AVE. According to Fornell & Larcker (1981), discriminant validity was also guaranteed in this study, and the details were reported in Table 3.

4.3 Structural Equation Modeling Analysis

Structural Equation Modeling (SEM) was employed to test the hypotheses (Table 4). The results illustrated that χ^2/df = 1.327 (< 3), GFI = 0.863 (> 0.8), TLI = 0.968 (> 0.9), CFI = 0.971 (> 0.9) and RMSEA = 0.034 (< 0.08). Thus, all model fit indices reached the thresholds of recommendations from Bagozzi & Yi (1988) and Hair et al. (2013).

Except hypothesis H_2 that reflected the relationship between environmental knowledge barriers and adoption intention was insignificant (p-value > 0.05), all remaining hypotheses were confirmed in this study. First, uncertain government policies and financial barriers were demonstrated to be the critical determinants of influence on adoption intention with β = -0.302 (p-value < 0.001; t-value = -4.958) and β = -0.258 (p-value < 0.001; t-value = -4.117), respectively. Second, product knowledge barriers had a negative impact on adoption intention with β = -0.192 (p-value < 0.01; p-value < 0.01) and brand trust barriers also constrained adoption intention with β = -0.163 (p-value < 0.001; t-value = -3.321). Owing to the lower-level effect, location-based barriers showed predicted ability to adoption intention with β = -0.148 (p-value < 0.001; t-value = -2.888), and technical barriers had the lowest influence with β = -0.110 (p-value < 0.001; t-value = -2.391). All independent factors explained 61.3% variation in adoption intention.

Table 4. Hypotheses testing and results of paths analysis

Hypotheses	β	t-Value	Findings
H_1: Financial barriers→Intention	-0.258***	-4.177	Accepted
H_2: Environmental knowledge barriers→Intention	-0.005^{NS}	-0.117	Rejected
H_3: Product knowledge barriers→Intention	-0.192**	-2.833	Accepted
H_4: Brand trust barriers→Intention	-0.163***	-3.321	Accepted
H_5: Uncertain government policies barriers→Intention	-0.302***	-4.958	Accepted
H_6: Technical barriers→Intention	-0.110**	-2.391	Accepted
H_7: Location-based barriers→Intention	-0.148**	-2.888	Accepted

Note: ***p-value < 0.001; **p-value < 0.01; NS: insignificant; β: standardised estimates

4.4 Multi-Group Analysis via Independent Sample t-Test

In order to evaluate the difference between rural and urban households regarding the perception of barriers, independent sample t-test was deemed appropriate to test for a statistically significant difference between two independent sample means (Allen et al., 2014). The sample was divided into two groups; while group 1 comprised 151 urban households, group 2 comprised 137 rural households.

Table 5. Results of independent sample t-test

Factors	Levene's Test		EVA/EVNA	Urban (n = 151)		Rural (n = 137)		p-Value	Findings
	F	Sig.		Mean	SD	Mean	SD		
FI	0.685	0.409	EVA	4.389	0.731	4.560	0.607	0.032	Accepted
EK	13.605	0.000	EVNA	4.073	0.939	4.129	0.578	0.538	Rejected
PK	11.957	0.001	EVNA	4.402	1.045	4.582	0.751	0.093	Rejected
UGP	3.252	0.072	EVA	5.681	0.724	5.563	0.609	0.137	Rejected
TE	0.022	0.882	EVA	3.768	1.085	4.366	1.166	0.000	Accepted
BT	8.278	0.004	EVNA	4.887	1.046	4.645	0.860	0.032	Accepted
LB	1.780	0.183	EVA	4.760	0.702	4.465	0.651	0.000	Accepted
INT	13.737	0.000	EVNA	3.099	0.788	3.428	0.548	0.000	Accepted

Note: SD – Standard deviation; EVA: Equal variances assumed; EVNA: Equal variances not assumed

Based on the t-test results (Table 5), differences (p-value < 0.05) existed between the perception of householders in the evaluations of financial barriers, technical barriers, brand trust barriers, location-based barriers and adoption intention. Meanwhile, the differences were not indicated in environmental knowledge barriers, product knowledge barriers, and barriers of uncertain government policies.

Differences of each factor mean between the two groups were demonstrated in Figure 3. The most significant difference in perception was technical barriers; as Mean = 4.366 was found in rural households while urban households had Mean = 3.768. Next, the perception of financial barriers in rural households with Mean = 4.560 was highly significant than urban households (Mean = 4.389). Location-based barriers indicated a significant difference when the perception of households from urban with Mean = 4.760 was higher than that of rural households with Mean = 4.465. Similarly, brand trust barriers of urban households (Mean = 4.887) were significantly higher than that of rural households (Mean = 4.645). Finally, rural households had a higher propensity for adoption intention (Mean = 3.428) than urban households (Mean = 3.099).

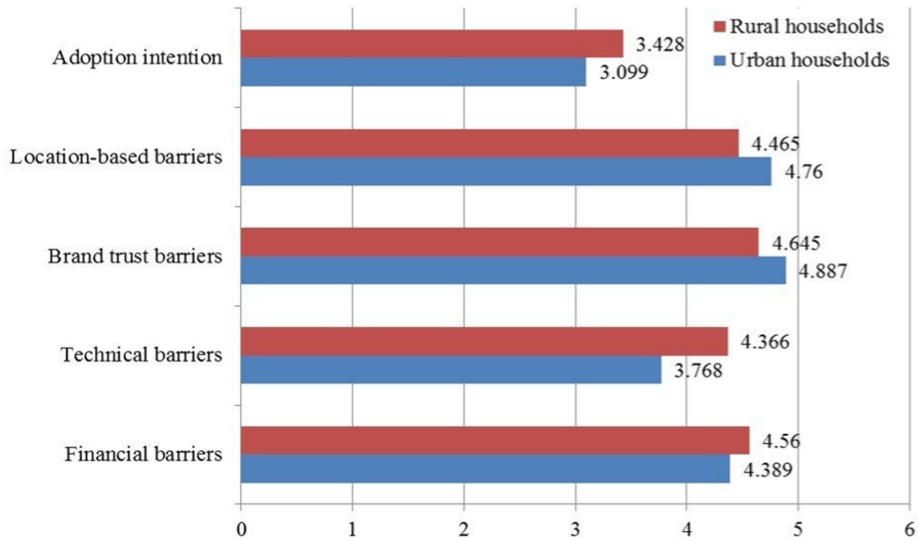

Figure 3. Comparison of perceived barriers

5. Implications and Conclusions

5.1 Theoretical Implications

This study developed a comprehensive framework for understanding household intentions to adopt PV solar technology in Vietnam, a country with significant potential in the global renewable energy supply chain. By validating measurement scales and employing a structural model that integrates multiple categories of barriers, the research enriched energy transition literature through a multidimensional approach encompassing psychological, contextual, and technical factors. The findings of this study helped address a notable gap in the literature regarding barriers to PV solar adoption, particularly in contrast to previous research that largely focused on motivational drivers (Kesari et al., 2018; Sun et al., 2018). In addition, this study significantly extended earlier work that examined policy frameworks through qualitative methods and case studies on renewable energy development (Do et al., 2020; Lo et al., 2018; Painuly, 2001) by providing empirical evidence from the customer perspective. These results offered valuable insights into the mechanisms through which barriers influenced PV solar adoption intention. By incorporating a diverse range of barriers into the structural equation modeling (SEM) framework, the study not only identified the most critical obstacles but also revealed how certain barriers might alter the effects of others. Notably, the highly explanatory power of the SEM model accounted for up to 63.1% of the variance in adoption intention and suggested that existing theories on barriers to renewable energy participation should be carefully reconsidered in the context of developing countries such as Vietnam. A more precise understanding of these influencing factors is essential for accurately assessing the dynamics of PV solar adoption in emerging markets.

A key theoretical contribution is the extension of cross-national perspectives on adoption barriers. The findings corroborate prior research from the United States, India, Turkey, Taiwan, and Hong Kong, while offering context-specific insights into the renewable energy landscape in Vietnam (Chekima et al., 2016; Do et al., 2020; Jiang & Kim, 2015; Lo et al., 2018; Rathore & Panwar, 2022). Notably, studies on pro-environmental behavior benefitted from these results, which identified barriers unique to household PV solar adoption, thus underscoring the interrelated influence of individual capability, product attributes, and contextual factors. More importantly, the barrier-focused framework explained up to 63.1% of the variance in adoption intention. This finding highlights the critical need to prioritize barrier analysis in energy transition efforts, rather than overemphasizing drivers and facilitating factors. It suggests that overcoming adoption resistance may be more influential in shaping sustainable behavioral outcomes than merely promoting expected benefits.

The results highlight two primary barriers: uncertainty in government policy and financial constraints. These findings reflect the regulatory instability of the renewable energy sector in Vietnam during the study period, particularly through delayed FiT payments and strategic policy revisions (Vu et al., 2023). Such macro-level disruptions diminish perceived household benefits and weaken motivation, to align with observations from other emerging economies. This outcome offers a critical perspective on the government's dual role in renewable energy development. While previous studies have emphasized the strong enabling influence of public policy (Huang &

Cheng, 2022; Rai & Beck, 2015), the present findings underscore potential drawbacks when policy design lacks consistency and stakeholder balance. Notably, uncertain government policies were not only identified as a key barrier in the structural equation modeling analysis but also emerged as the most strongly perceived obstacle among respondents, with a mean score of 5.625, the highest among all measured factors. This result highlights obvious limitations in the effectiveness of government policies to promote PV solar adoption. It underscores the need for a more nuanced evaluation of governmental efforts, hence suggesting that assessments should go beyond highlighting positive aspects and also critically examine shortcomings in policy design and implementation. Therefore, frameworks for evaluating government-related factors should be broadened, especially in the context of developing countries where persistent challenges in ensuring transparent governance and equitable benefit-sharing mechanisms may significantly influence the willingness of citizens to participate. This finding calls for a more comprehensive understanding of how policy environments shape adoption behavior and emphasizes the importance of addressing institutional barriers in emerging markets.

This study also revealed negative impacts of product knowledge and brand trust limitations on adoption intention though these factors were often underexplored in technology diffusion research within developing economies. The theoretical implications suggest that urban-rural segmentation mediates these perceptions, to reflect market dynamics that prioritize urban development while inadvertently deepening rural skepticism and information gaps. Location-specific and technical constraints further inhibited adoption intention. Dense urban population, limited installation space, and infrastructural deficiencies contribute to perceived infeasibility, hence advancing theoretical models of spatial limitations in sustainable technology adoption. Contrary to findings in other emerging markets, this study did not identify environmental knowledge deficiency as a significant barrier in Vietnam. Instead, the results suggest that potential adopters, typically individuals with higher incomes and education, possess adequate environmental awareness. The finding that environmental knowledge barriers did not have a significant impact in this study should not be interpreted as evidence that environmental factors were unimportant. Instead, it reflected a specific stage in the development of the PV solar market in an emerging economy such as Vietnam. This is particularly relevant when examining early adopters, who tend to be individuals with higher levels of education and incomes. In this context, practical economic, technical, and institutional factors have taken precedence and become the primary drivers of decision-making, often overshadowing barriers related to environmental knowledge. PV solar adoption in Vietnam is gradually viewed as an investment opportunity that can generate financial returns. As a result, concerns related to operational efficiency, long-term government support, and technical feasibility have emerged as top priorities for consumers. These considerations diminish the relevance of environmental knowledge barriers when included in a comprehensive barrier assessment model. This outcome also suggests the need to reevaluate traditional barrier constructs, such as environmental knowledge, in light of newly emerging expectations among individuals installing PV solar systems. It highlights the importance of identifying new types of barriers that are more closely aligned with investment motivations and performance expectations. Ultimately, this finding provides deeper insight into the challenges of PV solar adoption in emerging markets like Vietnam, where economic benefits increasingly outweigh environmental motivations.

5.2 Practical Implications

Besides theoretical implications, this study suggests several managerial implications to enterprises, technology providers, and policy-makers to develop PV solar network.

Firstly, uncertain government policies and financial barriers strongly influence the intention of household adoption. Thus, the Vietnamese Government should quickly unify strategic directions for developing renewable energy in the long term and have the plan to complete the FiT payment plans for households to guarantee the interests of stakeholders. Financial support, such as capital access policies and tax supports, should be offered to help households overcome financial barriers. For example, in this study, rural households had a higher adoption intention but perceived a high financial barrier. For businesses, it is necessary to have reasonable price policies, flexible payment, and launch trade-in campaigns to allow households to exchange the expired panels for a certain amount of money so as to sustain their PV consumption in long run.

Secondly, to overcome product knowledge and brand trust barriers, both the government and enterprises should enhance communication via multi-channel such as social network and online platforms. For brand trust barriers, the government should focus on promulgating standard, codes, product quality, and product certification as well as reinforcing supervisory capability with a variety of PV solar brands in the market. Enterprises need to increase brand trust through product labeling, and making and delivering environmental commitments.

Thirdly, under the lens of long-term development strategy, the government should focus on urban planning activities to support PV solar installation, especially in urban areas. Notably, PV solar production industry needs support to create high performance products with reasonable prices and products that are suitable for both natural and construction conditions in Vietnam. In addition, enterprises and technology providers should pay more attention to maintenance, installation, and product quality upgrade services to suit the business environment in Vietnam.

The study revealed that households in rural areas exhibited a higher intention to adopt PV solar systems compared to their urban counterparts. Rural respondents perceived location-based barriers as less significant, whereas urban households reported greater financial and technical challenges. These findings suggest that if governmental and corporate actors provide targeted financial incentives and technical assistance in urban areas, the market potential for PV solar products could expand beyond income-driven urban segmentation. Moreover, the results imply that PV solar businesses should develop geographically tailored marketing strategies that account for variations in income perception, installation feasibility, and technical support across regions.

5.3 Conclusions

Climate change, environmental pollution, and energy security remain major global challenges closely intertwined with economic development. Establishing a renewable energy supply chain characterized by lower CO_2 emissions and minimal environmental impact is a strategic solution adopted by many countries. Successfully transitioning from fossil fuels to renewable energy requires the active involvement of multiple stakeholders, with household participation playing a pivotal role.

This study presented a framework for evaluating barriers and motivations influencing the adoption of PV solar systems among Vietnamese households; it also highlighted the potential of Vietnam as an emerging market for developing renewable energy. The findings contribute to the broader discourse on renewable energy and sustainable consumption, offering both theoretical insights and practical implications for scholars, businesses, and policymakers seeking to expand the PV solar network.

Nonetheless, several limitations persist. The sample size was relatively small, while the control and moderator variables have yet to be incorporated. PV solar systems continue to be perceived as high-cost investments; therefore, potential customers are primarily concentrated among early adopters, i.e., individuals with strong educational backgrounds and higher income levels. Moreover, in the Vietnamese market, the decision to install PV solar systems is typically made by male members of the households. As a result, the respondents in this study were predominantly well-educated, financially stable, and male. This demographic concentration has implications for the generalizability of the findings, as the sample may not fully represent the broader population in Vietnam. To address this limitation, future research could consider expanding the scope of the survey, employing probability sampling techniques, and examining the influence of demographic characteristics on PV solar adoption behavior. Such efforts would help enhance the representativeness and depth of understanding in this emerging field. Notably, the explanatory power of the research model remains limited, thus indicating the need for further refinement. Future research should include broader perspectives of the stakeholders and more robust data collection method to enhance the applicability of the model.

Author Contributions

Conceptualization, T.D.V. and P.T.V.; methodology, T.D.V.; P.T.V. and T.H.N.; validation, H.N.N. and T.H.N.; formal analysis, T.D.V. and P.T.V.; investigation T.D.V. and P.T.V.; data curation, H.N.N. and T.H.N.; writing—original draft preparation, T.D.V. and P.T.V.; writing—review and editing, T.D.V. and P.T.V.; visualization, H.N.N.; supervision, T.H.N.; project administration, T.D.V. and P.T.V. All authors have read and agreed to the published version of the manuscript.

Funding

This study was supported by a grant from the Ministry of Education and Training, Vietnam, and Thuongmai University (Grant No.: B2025-TMA-05).

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Acknowledgements

The authors extended their sincere gratitude to Thuongmai University for providing a supportive academic environment that fosters scholarly exchange and collaboration. The enthusiastic assistance from the university has been instrumental in the successful completion of this research.

Conflicts of Interest

The authors declare no conflicts of interest.

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