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Exploring attitude and intention toward solar panel cleaning robots: Evidence from user insights

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A B S T R A C T

There is a global trend towards adopting green energy, with solar energy being the primary source derived from solar panel technologies. Solar panels can generate enough power for general and household use. However, to effectively function and serve their purpose, they require regular cleaning and effective maintenance, and robotic cleaning is among the current applicable technologies. This research aims to determine the intention of using solar panel cleaning robots in Thailand for individual solar panel users. The study was hinged on the extended C-TAM-TPB model. The quantitative survey study design was employed using primary data collected from individual solar panel users in their households. 419 respondents were used to collect the data. The C-TAM-TPB model proposed using reliability, validity, and model fitness which employed confirmatory factor analysis (CFA). They adopted structural equation modeling (SEM) in the evaluation of the variables' relationships and study hypotheses. Subjective norms and trust in technology, individual control perception, and awareness of renewable energy significantly and positively affected behavioral intention to use solar panel cleaning robots as indicated by the study. Trust in technology, awareness of renewable energy, and environmental concerns were found to be pivotal mediators to the attitude effect on individual users' intention to act in using solar panel cleaning robots. The authors recommend that to improve the adoption of solar panel cleaning robots; the concerned stakeholders should consider, firstly, enhancing trust in the technology of these robots, which is crucial, focusing on aspects like reliability, privacy, security, and reputation. Secondly, considering the influence of subjective norms, including perceptions from family, friends, colleagues, and experts, is essential. Perceived behavioral control should also be a focal point, encompassing self-efficacy, resources, and complexity. Moreover, increasing awareness of renewable energy and environmental benefits is vital to encourage individual adoption. The research also recommended that to encourage the adoption and use of solar panel cleaning robots, the aspects that should be emphasized include subjective norm, perceived behavior control, trust in technology, and awareness of renewable energy.

1. Introduction

The world is moving towards renewable energy sources, and solar power is among them. Solar energy has been used in space exploration since 1958, but it was not until recently that it became a useful energy source for people on Earth (Eschner, 2017). Solar energy has been utilized to heat water, generate electricity for cities, and make transportation a reality. The development of solar cells has been a leading cause to a dramatic increase in capacity over the recent years (Zhao et al., 2023). Al-Kayiem and Mohammad (2019) assert that solar power is premier and promising renewable energy sources. It's a reliable source of electricity allowing for provision at an affordable price and with zero pollution and greenhouse gas emissions. Solar power is said to be one of the major contributors to renewable energy, which has rapidly grown over the past years. Recent studies have shown that more than 900 million solar panels have been installed worldwide so far and counting. This number is expected to reach 1 billion by 2020, making solar power the foremost world's fastest-growing sources of energy (The World Bank, 2021).

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Solar panels are normally installed on roofs or flat surfaces where they receive maximum sunlight. Solar energy surfaces need regular and proper cleaning to absorb maximum energy from sunlight and generate electricity efficiently. The settling of dust materials on the so;ar panels' surfaces prevents them from proper energy absorption (Nahar Myyas et al., 2022). Statistics show that dust deposition on solar panels reduces their output by as much as 30% in just one month, making regular cleaning essential (Alghamdi et al., 2019). The research has also demonstrated that the solar panels' efficiency declines by 3-6% yearly, and this rate may be higher in countries that experience much dust, such as Thailand (Abuzaid et al., 2022; Nezamisavojbolaghi et al., 2023).

Additionally, Solar panel maintenance should be done to avoid any damages caused by dust or dirt particles present on them. In Thailand, the level of dust in the atmosphere is quite significant. It would accumulate dust and stains on the solar panels' surface at a higher rate, reducing the efficiency of the solar cells by approximately 35% (Nguyen et al., 2022; Nwaigwe et al., 2019). Specific cleaning techniques for solar panels necessitates the mitigate of the continued dust accumulation and regain the panel's efficiency (Aljaghoub et al., 2022). Normally, people clean solar panels manually. However, other more effective techniques exist, such as natural, automatic, and electrostatic (Farrokhi Derakhshandeh et al., 2021; Olorunfemi et al., 2022). Automatic cleaning entails using robot cleaners comprising computer-controlled machines such as sprinklers. There has been increased interest and adoption of robots in households and small and large plants to clean PV panels (Sarode et al., 2023; Aljaghoub et al., 2022; Bhatti and Tajuddin, 2022; Farrokhi Derakhshandeh et al., 2021; Venter et al., 2021).

This research explores different factors shaping the willingness to adopt solar panel technology cleaning robots in Thailand. These factors include attitude, ease of use perception, trust in technology, level of awareness in renewable energy, subjective norm, environmental concern, and tendency to incorporate solar panel cleaning robots. The study aims to generate valuable insights that benefit Thailand's household solar panel users. The objective will be met by answering the research questions above:

(i) What factors influence household users' intention in using solar panel cleaning robots in Thailand?

(ii) What are the direct and indirect factors influencing the intention to use solar panel cleaning robots among households' users in Thailand?

For the case of household users such as homeowners and individuals considering the adoption of solar panel cleaning robots, the research findings will provide valuable information on factors such as ease in the use, the trustworthiness of the technology, together with environmental benefits of these robots. From this knowledge, households can make informed decisions about incorporating this technology into their energy management strategies, potentially leading to improved energy efficiency and cost savings.

2. Literature review

Solar energy can be considered to be infinite making it a dependable and environmentally conducive source of power. Solar energy increases energy security and independence in many places with proper infrastructure and deployment due to electricity generation from solar energy (Durairaj et al., 2022, Nwaigwe et al., 2019). Solar power systems can be deployed at various sizes making them flexible to various energy demands, from individual residences to small-scale solar farms (Obaideen et al., 2021) Using solar energy helps to minimize the adverse environmental effects of using traditional sources of energy. It's production does not emit greenhouse gases making it an environmental friendly option in reducing carbon footprint and combating climate change (Nwaigwe et al., 2019). It's a greener choice that supports international efforts to move towards sustainable and low carbon energy systems. Since solar energy produces no greenhouse emissions while generating power makes it a clean and ecologically beneficial form of energy (Irfan et al., 2019, 2021; Olorunfemi et al., 2022). It helps minimize air pollution and slow down climate change. Additionally solar systems need little and have a lifetime maintenance which greatly lowers the operating expenses (Babajide & Brito, 2021; Hassan et al., 2023; Shamshirband et al., 2019), they are a long term cost effective option due to their longevity and less maintenance needs.

2.1 Cleaning Solar Panels Using Robots

To operate effectively and efficiently solar energy systems must be cleaned. Dust, grit, and debris that tend to build up on solar panels may seriously affect their functionality and lower power production (Colak et al., 2020). To maintain peak performance and guarantee the optimal use of sunlight regular cleaning is required (Jurasz et al., 2020), efficient cleaning methods and technologies, like robotic cleaning, Adapt to improve the overall solar panels performance to ensure their lifetime is increased (Ndeto, Njoka, Wekesa & Kinyua, 2024). Using cutting-edge sensors, and cleaning mechanisms robotic cleaning systems effectively remove dirt and debris from the panels navigational algorithms (Jurasz et al., 2020). It streamlines the cleaning procedures, improves cleaning accuracy, and reduces the possibility of panel damage by automating their operation.

Robotic technology is a potential approach to effective and automated solar panel cleaning. Robotic cleaning systems provide various benefits over conventional manual cleaning techniques, which consumes time, are labor-intensive, and may

be dangerous for employees (Jurasz et al., 2020). Using cutting-edge sensors, and cleaning mechanisms robotic cleaning systems effectively remove dirt and debris from the panels navigational algorithms (Shamshirband et al., 2019). Various studies acknowledge the autonomy of robotic cleaning systems moving around solar panel arrays, identifying soiled areas, and performing cleaning duties with little human assistance (Derakhshandeh et al., 2021: Shamshirband et al., 2019). Reduction in the need for personnel to conduct manual chores at heights reduces the labor needed for cleaning and improves safety (Jurasz et al., 2020),

2.2 Empirical Literature and hypothesis development

Individual perception of social norms and intention to use

Investigation in the correlation between individual perceptions of social norms and the intention to engage in behavior to use has been conducted in several situations, clarifying how social circumstances tend affect people's intentions to adopt a certain behavior or technology (Aji et al., 2020; Almrafee and Akaileh, 2024; Chidembo et al., 2023; Fazal et al., 2023, Ghosh and Satya Prasad, 2024). Aji et al. (2020) examined the influence of subjective norm and riba (interest) knowledge of the intention to utilize e-money in Indonesia. The results showcased that subjective norms, or perceived social pressure in participating in a behavior, significantly influenced people's intentions to use e-money (Devasagayam et al., 2023). According to findings, people are inclined to have the intention to use this financial technology where they believe that significant persons or society expects them to utilize e-money. Darmansyah et al. (2020) additionally analyzed variables influencing behavioral intentions towards utilizing Islamic financial technology in the context of this technology, proving how much subjective norms affected people's behavioral intentions, The results shows that social influence greatly impacts people's intentions in using Islamic financial technologies, Chidembo et al. (2023) found that subjective norms are central to and shape the decision of the users to adopt solar home systems. This hypothesis was developed derived from arguments put forth by the cited researchers.

H_1: *Subjective norm has a positive and significant influence on the behavioral intention to use Solar Panel Cleaning Robots.*

Perceived Behavioral Control and Behavioral Intention to Use

Perceived behavioral control and intention to use are correlated across domains. Many researchers have examined this connection and provide insights into how perceived behavioral control affects behavioral intentions (Abdillah et al., 2018; Ajzen, 2002; Cui et al., 2024; Gallardo et al., 2024; Hasan et al., 2024; Vamvaka et al., 2020), Vamvaka et al. (2020) scrutinizes the connection between entrepreneurial intention, attitude toward entrepreneurship, and perceived behavioral control. They discovered perceived behavioral control strongly affects individuals' intentions to become an entrepreneur, showing that those who feel that they more in control of their entrepreneurial behaviors are more likely to have those intentions, and entrepreneurial orientation and performance (Culhane and Mangaliso, 2023), Moreover, Teo et al. (2019) investigated the variables affecting college students' intentions in using Moodle's e-learning platform where he discovered that perceived behavioral control positively affected the intentions of students to utilize Moodle. Students were more likely to use the platform when they controlled their capacity. The following hypothesis was proposed after a review of the relevant literature,

H_2: *Perceived behavioral control exerts a positive and significant influence on the intention to use solar panel cleaning robots.*

Attitude and intent to utilize

Disposition and intent to act related to the use may be seen across different situations and domains, which has helped in the clarifications of the variables affecting conduct intention (Francis et al., 2019; Gallardo et al., 2024; Bharadwaj and Deka, 2021; Thirakulwanich and Sawmong, 2022; Wiastuti et al., 2022). From the research by Wiastuti et al. (2022), users' behavioral intention is adversely influenced by attitude, which focuses on food delivery apps. The possibilities that users would utilize meal delivery apps increased with their attitude towards efficiency and convenience. Francis et al. (2019) researched the topic relationship between attitude, behavioral norm, perceived control over behavior, and consumer intentions to use Islamic goods in the setting of Islamic banking services.
Favorable attitudes towards them were discovered which impacted the usage of Islamic goods leading to the development of the following hypothesis.

H_3: *Attitude provides for a good influence on the behavioral intentions of using solar panel cleaning robot.*

Confidence in Technology and Intention to Utilize

Relationship between trust in technology and intention to utilize it has been a subject of several studies based on prior research (Abbas et al., 2021; Ayanwale and Ndlovu, 2024; Chao, 2019; Gallardo et al., 2024; Hasan et al., 2024; Zhou et al., 2019). Chao (2019) expanded on Unified Theory of Acceptance and Utilize of Technology (UTAUT) model and investigated the intention to use mobile learning. The research showcased that confidence in technology greatly impacted behavioral intentions in utilizing mobile learning. People are most likely to have good intentions when they trust technology. In their analyses, Ayanwale and Ndlovu (2024) found that students who trusted chatbots and perceived benefits for using them showed a strong intention to utilize them in their studies. Zhou et al. (2019) also investigated the variables impacting Chinese. Seniors' behavioral intentions to utilize telehealth services. They used an extended Technology Acceptance Model (TAM) in their investigation. The findings showed that trust in technology highly impacted behavioral intention to exercise telehealth services, and senior citizens were more likely to use them. As a result, these hypotheses were developed.

H_4: *Trust in technology has a positive and significant influence on the intention to use Solar Panel Cleaning Robots in Thailand*
H_{9a}: *Trust in technology significantly mediates the effects of attitude on behavioral intention to use Solar Panel Cleaning Robots in Thailand*

Awareness of Renewable Energy and Behavioral Intention to Use

Different studies acknowledge a substantial relationship between behavioral awareness of renewable energy intention and behavioral intention to utilize it (Ashinze et al., 2023; Fazai et al., 2023; Ghosh and Satya Prasad, 2023: Nazir and Tian, 2023). Ashinze et al. (2021) developed a multidimensional model that connects consumer behavior and purchasing intentions with sustainable renewable energy. From the research, consumers' behavioral intentions in using renewable energy is approvingly influenced by more awareness. When people have more positive attitudes and intentions they most likely accept and use renewable energy technology due to their awareness of the renewable energy sources, their advantages, and their potential for sustainability. In a similar research, Nazir and Tian (2022) suggests that attitude mediated the association among variables influencing purchasing intentions and the willingness to pay for the renewable energy. The research discovered that customers' attitudes which affect their readiness to spend on and utilize renewable energy sources are strongly impacted by their awareness and understanding of renewable energy. Raising awareness precedes the emergence of favorable attitudes and intentions towards renewable energy in this scenario. From above, the following hypotheses were developed.

H_5: *Awareness of renewable energy significantly impacts the behavioral intention to use Solar Panel Cleaning Robots in Thailand.*
H_{9b}: *Awareness of renewable energy significantly mediates the impacts of attitude on behavioral inclination to use Solar Panel Cleaning Robots in Thailand.*

Environmental concern and Behavioral Intention to Use

Prior studies have investigated the correlation among environmental concerns and behavioral intentions (Diep Le, 2021; Dwivedi et al., 2022; Liu et al., 2020; Wang and Mangmeechai, 2020; Yang et al., 2020). A positive connection between environmental Diep Le (2021) discovered concern with the intention of making environmentally friendly purchases. In a study on the green shopping habits of Vietnamese consumers, which found that they probably indicate their willingness and intention to purchase environmentally friendly items when they have greater concerns about the environment. Elian (2022) explored relationship between environmental attitudes, perceived danger of privacy, and intention to adopt smart home systems in Indonesia. The findings proved that environmental attitudes favorably affected the inclination to utilize a smart home system. According to research, people with solid environmental convictions are more likely to declare their intention in the acquisition and utilizing smart home technologies that promote environmental sustainability. From the above assertions, the following hypotheses were proposed.

H_6: *Environmental concerns have a positive influence on the intention to use solar panel cleaning robots.*
H_{9c}: *Environmental concern significantly mediates the impacts of attitude on propensity to employ Solar Panel Cleaning Robots.*

Perceived Usefulness and Attitude

Online education, consumer-brand interactions, and e-government services are just a few examples of research areas where the connection between perceived usefulness and attitude has been studied.(Jang and Song, 2021, Kelly and Palaniappan, 2023; Singh and Singh, 2020, Toros et al., 2024; Wang et al., 2023), Jang and Song (2021) studied on moderating role of perceived usefulness and mediating the role of learning attitude on the relationship between interaction and pleasure in interactive online education. Their study revealed that views towards online education are significantly influenced by

perceived usefulness. Students' attitudes towards the learning process are favorably affected when they have the belief in the teaching to be valuable. Similarly, Singh and Singh (2020) research on mediating role of the perceived usefulness and brand attitude influence the relationship between consumer-brand metrics. According to the findings of their study, customers' attitudes toward a brand are suggested because perceived usefulness acts as a mediator between consumer-brand measurements and brand attitude.

H_7: *Perceived usefulness demonstrates a significant influence on attitude towards intention to use Solar Panel Cleaning Robots in Thailand*

Perceived Ease of Use and Attitude

Interconnection among technology's perceived as easy to use and attitude is acknowledged by a variety of researchers. (Kelly et al., 2023; Sarkam et al., 2022; Toros et al., 2024; Yazeed et al., 2021), For instance, Sarkam et al. (2022) studied the factors that help customers to decide whether or not they will use an electronic payment system. The observations were that clients' perspective on the e-portion structure's accommodation out and out impacted their points of view toward it. When they believe a system to be simple, they are more likely to like it. Moreover Yazeed et al. (2021) studied the relationship between perceived usefulness, usability, online trust, and the intention to purchase online. They discovered that perceived ease of use conclusively impacted customer sentiments towards online purchases. The findings show that people's attitudes about online purchases improve when they think online shopping platforms are simple. Based on the literature discussion, hypothesis 8 was proposed.

H_8: *Perceived ease of use has a significant indirect influence on the intention to use Solar Panel Cleaning Robots in Thailand*

3. Conceptualized Model

The conceptualized model was developed by evaluating literature review and the proposed hypotheses. Two theories, Technology Acceptance Model (TAM) (Davis, Granić & Marangunić, 2023; Al-Adwan et al., 2023; Alsyouf et al., 2023) and the Theory of Planned Behavior (TPB) (Albayati, Alistarbadi & Rho, 2023; Rozenkowska, 2023; Hamid & Azhar, 2023)., have been integrated to form the Combined Technology Acceptance Model and Theory of Planned Behavior (C-TAM-TPB). The dependent variable was the behavioral intention to use solar panel cleaning robots, while the mediating variable was the attitude towards solar panel cleaning robots. The independent variables were perceived behavioral control, subjective norm, trust in technology, awareness of renewable energy, environmental concern, perceived usefulness and ease of use.

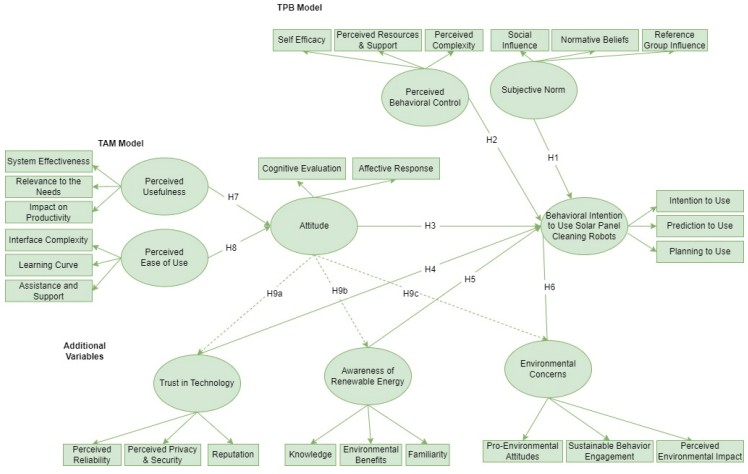

Fig. 1. Conceptual framework of the study

Source: Authors Development

4. Methodology

This research investigated the intention to use solar panel cleaning robots in households in Thailand using the C-TAM-TPB model. Several studies have used this model previously (Naufal et al., 2024; Wang, Chung & Den Yeoh, 2023; Tang & Jiang, 2024). The chosen research design was a quantitative one, with a specific approach on cross-sectional type to collect data from a diverse sample of households in Thailand. The survey instrument, or rather the questionnaire for data collection,

developed based on the extended C-TAM-TPB model, incorporating additional variables (trust in technology, awareness of renewable energy, and environmental concern) related to solar panel cleaning robots. The study population comprised households in Thailand that use solar panel technology and robotic cleaning techniques to clean them. Since this population is large for Thailand, a representative sample got selected from which the data was collected.

This research adopted the probability sampling method, which involves random selection, providing each member of the population with a known chance of being included in the sample. Simple random sampling technique was adopted. Based on item-to-variable ratio, several are proposed being 15:1, 20:1 according to Hair et al. (2019). The recommended observations per independent variable are 15 to 20. The study has nine latent variables with three observed variables each. Therefore, the total observed is 26 in this research. Adopting the 15:1 ratio, the minimum sample size would be 390 (26*15) respondents. Therefore, a higher sample size will be targeted to get the recommended minimum sample size.

The estimated sample was collected from solar panel users in Thailand. All four Thailand regions were considered to ensure the representation of Thailand's entire population in the data: the North Region, North Eastern Region, Central Region, and Southern Region. The stratified random sampling was adopted to develop four regions from which the data was collected. From these regions, strata comprised three towns in each region. These towns were randomly selected to be included in the representative sample. From these towns, equal samples of respondents were selected from which the data was collected.

4.1 Research instrument development

The research adopted a structured questionnaire as a research instrument. The questionnaire was designed to gather data on the study variables, referencing the research questions and hypotheses. The questionnaire comprised questions for each observed variable, which are, in this case, referred to as the measurement items. The questions were chosen from the previous studies and modified to fit the context of this study. The exogenous latent variables are as follows. The perceived usefulness comprised three observed variables (System Effectiveness, Relevance to the Needs, and Impact on Productivity). They were derived from the studies of Chen and Aklikokou (2020), Akther and Nur (2022), and Widjaja and Widjaja (2022). The Perceived Ease of Use had three observed variables (Interface Complexity, Learning Curve, and Assistance and support) sourced from Keni (2020), Giraldo, Benjumea-Arias, Valencia-Arias and Montoya-Restrepo (2021), and Widjaja & Widjaja (2022). The perceived behavioral control had three observed variables (Self- Efficacy, Perceived Resources and support, and Perceived Complexity) and were derived from Banerjee and Ho (2020), Sugandini et al. (2018), Ajzen (2002), and Yuan (2021). The latent variable "subjective norm" had three observed variables (Social Influence, Normative beliefs, and Reference group influence) derived from Cialdini and Goldstein (2004); Aschwanden et al. (2021); Lee, Yeh, Chang, Yu & Tsai (2022). Trust in technology had three observed variables (perceived reliability, perceived privacy, and security, reputation) derived from Fitrianie et al. (2021), Alswaigh and Aloud (2021), and Manrai and Gupta (2020). The latent variables of awareness of renewable energy had three observed variables (knowledge about renewable energy, awareness of environmental benefits, and familiarity with renewable energy) developed by Maciaszczyk et al. (2022), Al-Marri et al. (2018), and Ayyoub and Radaydeh, (2021). The latent variable of environmental concerns had three observed variables (pro-environmental attitudes, sustainable behavior engagement, and perceived environmental impact) derived from Nasirov et al. (2018), Chen et al. (2021), and Shukla and Kumar (2020).

The study had one endogenous latent variable, namely behavioral intention to use, containing three observed variables (Intention to Use, Prediction to Use, and Planning to Use). They were developed with reference to Chao, (2019), Tseng et al. (2019), Shiau and Chau (2016), and Aditia et al. (2018). The study had one Mediating latent variable named attitude. It had two observed variables (Cognitive evaluation and Affective response) derived from Angelia et al. (2021), Abdekhoda and Zarea Gavgani (2017), Haddock and Maio (2008), and Ajzen (2014). The data analysis process was conducted using various methods. The first was demographic analysis, which evaluated the demographic characteristics of the household users of the solar panel respondent group. Descriptive statistics of the various observed and latent variables were used to measure the respondents' responses to the various research items. The confirmatory factor analysis (CFA) was conducted to evaluate the model fitness tests of the adopted conceptual framework. Empirical analysis was used to analyze the existing relationship between the study constructs. The first was structural equation modeling (SEM), evaluating the relationship between the study variables. This addressed hypotheses 1-9. Ethical considerations were also made in this research. First, proper authorization from the relevant academic officials was obtained. Secondly, the participants of the study were served with consent to participate in the study and were free to participate or opt out at any time during the study. Additionally, the data collected were kept confidential and only used for the purpose of this study.

5. Results

The respondents' characters are presented in Table 1. The results show that for gender variables, men were the majority (52.0%) followed by women (38.9%) while others were the least at 9.1%. Considering the age variable, 41 – 50 years was the majority age group (31.3%), followed by 31 – 40 years (22.0%) and then 21-30 years (17.4%). The other category that was evaluated was the education level of the respondents. The majority were those with High school or diploma (43.9%) followed by those with Junior High School or Lower (25.6%) and then those with bachelor’s degree (20.5%) and finally those with Post Graduate or Higher (10%).

Table 1
Demographic characteristics for individual users

Character	Categories	Frequency	Percent
Gender	Men	218	52.0
	Women	163	38.9
	Other	38	9.1
	Total	419	100
Age(yrs)	18-20	26	6.2
	21-30	73	17.4
	31-40	92	22.0
	41-50	131	31.3
	51-60	77	18.4
	>60	20	4.7
	Total	419	100
Education	Junior High School or Lower	107	25.6
	High School / Diploma	184	43.9
	Graduate Degree	86	20.5
	Post Graduate or Higher	42	10
	Total	419	100
Occupation	Student	59	14.0
	government employed	106	25.3
	company employed	136	32.5
	self employed	118	28.2
	Total	419	100
Monthly Income (Baht)	<= 10,000	81	19.3
	> 10,000 – 20,000	94	22.4
	> 21,000 – 30,000	97	23.2
	>31,000 – 40,000	84	20.1
	>41,000	63	15.0
	Total	419	100.0
Amount of Electricity Units Consumption	Less than or Equal to 4,999 Units	87	20.8
	More than 5,000 Units – 9,999 Units	70	16.7
	More than 10,000 Units – 29,999 Units	91	21.7
	More than 30,000 Units – 39,999 Units	110	26.2
	More than 40,000 Units and higher	61	14.6
	Total	419	100.0

Considering the occupation, the majority were those employed by companies (32.5%), followed by those who were self-employed (28.2%), then government-employed (25.3%), and then students (14.0%). Monthly income was evaluated for the respondents. The majority indicated that most of the respondents earned between 21,000 Baht – 30,000 Baht (23.2%), followed by those who earned between 10,000 Baht – 20,000 Baht (22.4%), and then those who earned 31,000 Baht – 40,000 Baht (20.1%), and then those who earned less than or Equal to 10,000 Baht (19.3%) and lastly those who earned More than 41,000 Baht and higher (15.0%). The amount of electricity unit consumption was evaluated, where the majority indicated that they spent 30,000 Units – 39,999 Units (26.2%), followed by those who spent 10,000 Units – 29,999 Units (21.7%), and lastly, those who spent more than 40,000 Units and higher (14.6%).

5.1 Second order model CFA analysis

The second-order model CFA was implemented to investigate the overall fitness of the model. The results for the CFA indicated that the chi-square was significant ($\chi2$ [250] = 830.375, $p < 0.01$), also expressed as $\chi2$ /df ratio = 3.322. it satisfied the required threshold of <5.0 (Schumacker and Lomax, 2004). Evaluating other fitness indices indicated that CFI = 0.929, TLI = 0.908, IFI = 0.930, and NFI = 0.903. These values satisfied the required threshold of >0.90. The RMSEA = 0.075, which was within the required threshold of <0.08, while GFI =0.894 which was within the required threshold of >0.80. Since these statistics were satisfactory, it was conclusive that the proposed model fitted well to the data as illustrated in Table 2.

Table 2
CFA results second order model CFA analysis

Fit index	Threshold	Stat value	Satisfactory?
$\chi2$ /df ratio	<5.0	3.322	Yes
CFI	>0.90	0.929	Yes
TLI	>0.90	0.908	Yes
IFI	>0.90	0.930	Yes
NFI	>0.90	0.903	Yes
RMSEA	>0.080	0.075	Yes
GFI	>0.80	0.894	Yes
Conclusion			**Model Fit**

In addition to the model fitness, loading factors, AVE, and convergent reliability (CR) were evaluated for each latent variable and their observed variables. The threshold for factor loadings is >0.5, for AVE is 0.5, while that of CR is 0.7 (Fornell and Larcker (1981), Nunnally & Bernstein, 1994), (Segars, A. H. (1997). Factor loadings ranged from 0.798 (SYE) to 0.885 (IP) for the observed variable perceived usefulness. The CR was 0.869, while the AVE was 0.689. These statistics satisfied all the required thresholds. Factor loadings ranged from 0.789 (AR) for the observed variable attitude to 0.838 (CE). The CR was 0.797, while the AVE was 0.662. These statistics satisfied all the required thresholds. For the observed variable, perceived behavior control factor loadings ranged from 0.840 (SE) to 0.882 (PC). The CR was 0.892, while the AVE was 0.733. These statistics satisfied all the required thresholds. The observed variable's subjective norm factor loadings ranged from 0.715 (NB) to 0.892 (RG). The CR was 0.835, while the AVE was 0.630. These statistics satisfied all the required thresholds. For the observed variable, perceived ease of use standardized beta was from 0.708 (LC) to 0.878 (AS). The CR was 0.845, and the AVE was 0.648. These statistics satisfied all the required thresholds. For the observed variable, trust in technology standardized beta was from 0.257 (RT) to 5.053 (PRE). The CR was 0.880, while the AVE was 0.728. These statistics partially satisfied all the required thresholds. For the observed variable awareness of renewable energy, the factor loadings ranged from 0.735 (KN) to 0.92 (FM). The CR was 0.885, and the AVE was 0.722. These statistics satisfied all the required thresholds. For the observed variable environmental concern, the standardized beta was from 0.851 (PEI) to 0.91 (PEA). The CR was 0.916, while the AVE was 0.784. These statistics satisfied all the required thresholds. The standardized beta was from 0.871 (IU) to 0.903 (PLU) for the observed variable behavioral intention to use. The CR was 0.917; correspondingly, the AVE was 0.786. These statistics satisfied all the required thresholds.

Table 3
CFA results for model fitness

		Factor Loadings					
Latent Variable	**Observed Variable**	**Estimate**	**S.E**	**Beta**	**T-stat**	**CR**	**AVE**
P.U	IP	1.0000		0.885		0.869	0.689
	RN	0.8570	0.043	0.804	19.735**		
	SYE	0.8120	0.042	0.798	19.497**		
AT	CE	1.0000		0.838		0.797	0.662
	AR	1.0900	0.067	0.789	16.384**		
PBC	SE	1.0000		0.84		0.892	0.733
	PR	1.0160	0.045	0.846	22.43**		
	PC	1.1800	0.063	0.882	18.718**		
SN	SI	1.0000		0.763		0.835	0.630
	NB	0.8850	0.055	0.715	16.062**		
	RG	1.2950	0.088	0.892	14.676**		
PEU	AS	1.0000		0.878		0.845	0.648
	LC	0.6670	0.046	0.708	14.621**		
	IC	0.8080	0.054	0.819	15.096**		
TT	RT	1.0000		0.257		0.880	0.728
	PP	6.2370	6.655	2.046	0.937		
	PRE	16.0100	18.138	5.053	0.883		
ARE	FM	1.0000		0.92		0.885	0.722
	EB	0.9500	0.035	0.882	26.834**		
	KN	0.8060	0.047	0.735	17.015**		
EC	PEI	1.0000		0.851		0.916	0.784
	SB	1.1200	0.049	0.894	22.806**		
	PEA	1.1380	0.055	0.91	20.654**		
BIU	IU	1.0000		0.871		0.917	0.786
	PU	1.0260	0.042	0.885	24.156**		
	PLU	1.0230	0.043	0.903	23.698**		

5.2 Empirical analysis for individual users

SEM got employed to find out the relationship among the study variables. SEM analysis for individual users was conducted using the variables and the models presented in Table 4.

The relationship between the study variables indicates that SN significantly positively affects BIU (β = 0.148, p=0.002), confirming H1. PBC positively influences BIU (β = 0.082, p=0.005), supporting H2. The results indicated that AT has an insignificant positive influence on BIU (β = 0.057, p=0.382), rejecting H3. Trust was found to have a positive significant effect on BIU (β = 0.338, p=0.000) supporting H4. ARE was found to constructively influence BIU (β = 0.049, p=0.043), supporting H5. EC was found to have a negative insignificant effect on BIU (β = -0.012, p=0.486), hence rejecting H6. PU significantly influences AT (β = 0.511, p=0.000), hence accepting H7. PEU had a significant and positive influence on AT (β = 0.357, p=0.000), hence supporting H8. The results for mediation indicated that TT does mediate the effects of AT on BIU (β = 0.002, p=0.615); ARE mediates the effects of AT on BIU (β = -0.008, p=0.081); and EC significantly mediates the effects of AT on BIU (β = 0.003, p=0.005). Hence, H9a, H9b and H9c were supported.

Table 4
Latent and observed variables used in the model

Latent Variables	Observed Variables	Symbols
Perceived Usefulness (PU)	System Effectiveness	SYE
	Relevance to the Needs	RN
	Impact on Productivity	IP
Perceived Ease of Use (PEU)	Interface Complexity	IC
	Learning Curve	LC
	Assistance & Support	AS
Perceived Behavioral Control (PBC)	Self- Efficacy	SE
	Perceived Resources & Support	PR
	Perceived Complexity	PC
Subjective Norm (SN)	Social Influence	SI
	Normative beliefs	NB
	Reference group influence	RG
Trust in Technology (TT)	Perceived Reliability	PRE
	Perceived Privacy & Security	PP
	Reputation	RT
Awareness of Renewable Energy (ARE)	Knowledge about Renewable Energy	KN
	Awareness of Environmental Benefits	EB
	Familiarity with Renewable Energy	FM
Environmental Concerns (EC)	Pro-Environmental Attitudes	PEA
	Sustainable Behavior Engagement	SB
	Perceived Environmental Impact	PEI
Behavioral intention to use (BIU)	Intention to Use	IU
	Prediction to Use	PU
	Planning to Use	PLU
Attitude (AT)	Cognitive evaluation	CE
	Affective response	AR

The results for the relationship between study constructs is presented in the table below.

Table 5
SEM analysis model results

Path Relationship			Estimate	S.E.	C.R.	P
Direct Effects						
SN	→	BIU	.148	.048	3.085	.002
PBC	→	BIU	.082	.030	2.789	.005
AT	→	BIU	.057	.065	.875	.382
TT	→	BIU	.338	.066	5.148	***
ARE	→	BIU	.049	.024	2.023	.043
EC	→	BIU	-.012	.018	-.696	.486
PU	→	AT	.511	.046	11.174	***
PEU	→	AT	.357	.054	6.622	***
Indirect Effects						
AT → TT → BIU			.002	.001	2.589	.000
AT → ARE → BIU			-.008	.002	-3.5281	.003
AT → EC → BIU			.003	.0001	1.9641	.002

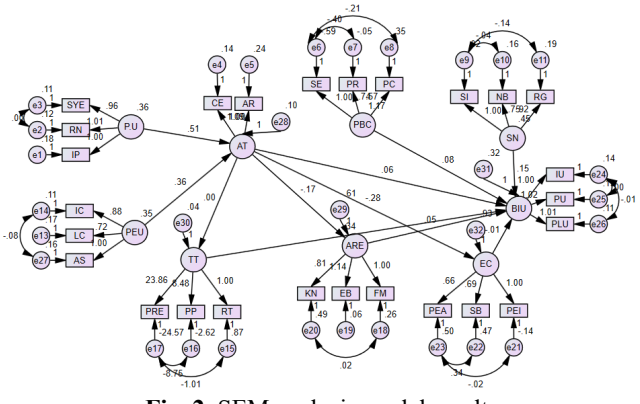

Fig. 2. SEM analysis model results

6. Discussion

In this section, a discussion of the research is conducted addressing the study's research objectives. The research questions addressed the following: Factors influencing household users' intention to use solar panel cleaning robots in Thailand; Moreover, what direct and indirect influences affect the intention to utilize solar panel cleaning robots among households in Thailand. The relevance of subjective norms towards intentions of using the solar panel cleaning robots in Thailand is studied in detail as per the obtained results. People's subjective normative influences were observed to have a strong and a beneficial impact on behavioural intention, and they are found to be significant (ß 0.148, p=0.002). Scholarly articles from journal reviews have examined the association between the same variables. Such relationships explore social conditions and accordingly influence people's mindsets that are likely to rule out certain behaviours or technology. A report by Aji et al. in 2020 showed that people's behavioural intentions to use e-wallets, which is a social stimulus or perception that there is social pressure on them to behave in a certain way were mainly determined by subjective norms. Similarly, Darmansyah et al. (2020) also explored the determinants of behavioral inclination towards using Islamic financial technology as well as its consequences which showed that a person's attitude to practicing the Islamic banking or financing system is influenced by how they perceive other closely related individuals. The results of the study align with Chidembo et al. (2023) that subjective norms exhibited the highest impact towards adopting solar home systems. So, it can be reckoned that subjective norm aspects play a great role in determining individual solar panel cleaning robots' intentions in Thailand.

This section also investigates the connection between behavioural control underestimation and the intention to set up solar panel cleaning robots in Thailand. The findings suggest BIU (positive residual of 0.082, and remarkable statistic [p=0.005]). These findings bear a close resemblance with those presented in Vamvaka et al. (2020), where the link between entrepreneurial intention, its control, and attitude toward entrepreneurship was subject to a study. Consistently, their findings established the influence of the perceived behavioural control over individuals' intentions to become entrepreneurs in a way that those with a high level of control of their behaviours around the business activity showed a positive attitude favouring such intentions. Furthermore, Teo et al. (2019) researched the factors that will influence college students' e-learning Moodle intention and uncovered that particularly, perceived behaviour control affected students' intention to use Moodle positively. It is suggested, accordingly, that the sense of control over one's behaviour is one of many important factors that define an individual's intention to use solar panels.

Attitude and the behavioural intention to adopt the solar panel cleaning robots in the research section are probed. The results showed that affecting behavioural intentions to use solar panel cleaning robots was not highly influential, meaning attitude (B = 0.057, p=0.382). Nevertheless, their findings run counter-core to those of Francis et al. (2019), who reported having observed individuals' preferences towards Islamic commodities being positively influenced by their attitude. In regard to this specific matter, Wiastuti et al. (2022) who focused on food delivery apps discovered that users' behavioural intention is significantly affected by their attitude. In the era of meal delivery apps, their popularity is growing fast, and so, the attitude of the users toward efficiency and convenience is the decisive factor. The outcome highlights that the bond was significant but not important.

The significance trust holds on consumers' readiness to adopt solar panel cleaning robots was investigated. The results confirmed a positive influence of trust on BIU. The estimated regression coefficient was 0.338 and the p-value was 0.000. It is also supported by the literature by Meyer-Loftus (2017) where the author pointed out that trust in technology has a strong impact on the behavioural intention to use mobile learning. It is probably the case that people with positive attitudes will consider technologies appropriate and worth their while. Another study with the same finding was by SuGao (d Gao(2020), which stated that the order of such behaviour to use such technology with high intention came from the level of trust that they have in reaction they find enjoyable and amusing.

Research that focuses on the influence of awareness of renewable energy on behavioural intention to have solar panel cleaning robots shows that A-RE has a significant effect on BIU ($\beta = 0.049$, $p = 0.043$). Therefore, consciously encompassing renewable energy factors, such as increasing the knowledge regarding renewable energy sources, realizing the environmental benefits, and getting familiar with renewable energy sources, will further encourage individuals to use self-cleaning solar panel-related robots. These data were backed by the factor that people tend to believe and use renewable energy technologies when they are properly informed, have a positive opinion towards renewable energies and possess intentions of using them (Even the same researchers engaged in different studies in 2021 where they found similar findings with these).

This section evaluated the concept of environmental protection and looked at the modulator role played towards the intention of solar panel cleaning robots. The outcomes showed that the environment consciously was a pool of -0.012, and the value was 0.486. The fact that people do not seem to consider environmental risk justifies their preference for solar cleaning robots. However, it must be noted that as far as individuals are concerned, there is no correlation between our solar cleaning robots and environmental issues. The results are in dissonance with the literature (Diep Le, 2021; Dwivedi et al., 2022; Liu et al., 2020; Wang and Mangmeechai, 2020; Yang et al., 2020) that emphasized at a strong and conducive relationship on environmental concern and on the objective to purchase ecologically sound devices and commodities. The environmental concern aspects considered in this case were pro-environmental attitudes, sustainable behaviour engagement, and perceived

environmental impact. One possible explanation for this deviation could be that individual users prioritize their electricity expenses and view solar cleaning robots as a way to reduce them. They also view these robots as extensions of themselves that enable them to multitask and accomplish daily objectives rather than considering their actions from an environmental sustainability perspective.

The impacts of perceived usefulness on the attitude towards solar panel cleaning robots was investigated in this section. The results indicated that PU exerts a significant positive influence on AT (B 0.511, p=0.000). This alluded that if there were an improvement in the perceived usefulness aspects such as system effectiveness, relevance to the needs, and impact on productivity about solar panel cleaning robots, then attitude towards them would be increased. These results were validated by the article written by Singh and Singh (2020) aimed at discovering the intermediating influence of perceived utility and brand attitude on the relationship between the consumer-brand factors. The findings of their studies were through perceived usefulness as a mediating variable between consumer-brand measurements and brand attitude. The research indicated that brand attitude is derived from the perception that the company is useful to the consumers. Concerning the effect of NASA's human-robot compatible design on PS, the results manifest that the PUC Yields a beneficial and statistically meaningful effect on AT (B=0.357, p=0.000). This study holds that ease of use factors, such as interface complexity, learning curve and help and support about the solar cleaning robots, would be one of the main factors determining users' attitudes individually. A study conducted by Sarkam et al. (2022 revealed that it is a factor that affects the customer perception of the e-payment system and the higher the simplicity of using the e-payment system the higher the positive perception of the customers towards the e-payment system. The results have been that people like a system more and more if they consider it user-friendly.

To reach a deeper understanding of the process of attitudinal formation and behavioural intentions regarding individual users of solar robot cleaners, a study was done to see how these factors such as trust in technology, consciousness of renewable energy, and environmental concern affect the mediated relationships of peoples' attitudes on that particular technology. The data indicate that the belief in technology, the awareness of renewable energy and the environmental concern are the factors that allow the attitude to significantly influence individual users´ behaviour regarding the use of solar panel cleaning robots. It might be like pro-environmental mindsets, environmentally friendly behaviour commitment, and perceived environmental impact made them see things that would be so useful to have solar cleaning robots.

7. Conclusion

This research aimed to investigate the intention to use solar panel cleaning robots in Thailand. The research was driven by the argument that solar energy stands out as a common and most promising form of renewable energy harnessed from sunlight. On this account, solar panel cleaning robot technology would be introduced as one of the technologies that was worth executing. Research was based on the consideration of the extended C-TAM-TPB model. The primary data upon which this research is anchored is the solar panel users that were interviewed. The intended size of the sample was 400 respondents. Convergence and differentiation in validity of the model were interpreted using Confirmatory Factor Analysis (CFA) while reliability tests were also performed. The causal relationships between the study factors at the basis of the research question obtained with the help of structural equation modelling.

The research indicated that the so-called subjective norms, perceived behavioural control, trust in technology, and awareness of renewable energy have significant correlations to the behavior intention to use robots for cleaning solar panels on an individual basis. Specifically, it could be confirmed that the attitude toward using this technology is promoted by trust in technology, environmental awareness, and concern with renewable energy, which gives a mediating effect towards the intention of household members to utilize solar panel cleaning robots. Research suggested the C-TPB-TAM model as a revised one for determining the intention towards adopting solar robots in the cleaning industry. Rather, it is the responsibility of various stakeholders including all to consider how to boost the acceptance of the solar panel cleaning robots. However, its first prerequisite is exclusively building trust in the technology of these robots, for example, reliability, privacy, security, and reputation. For instance, taking into account the subjective norms, namely social norms and reference groups such as family, friends, peers, and experts impact a person greatly also. Despite the varied habit-building techniques suggested, attention should be paid to perceived behavioural control — a multifaceted concept including self-efficacy, resources, and complexity. Furthermore, to facilitate and trigger individual acceptance is through widespread sharing of energy knowledge to the population.

The study was considered successful. However, several limitations could be highlighted. First, the study focused on individual users, potentially overlooking other stakeholders like government bodies, regulatory agencies, or environmental organizations that could play crucial roles in technology adoption. Secondly, the findings may need to be revised in generalizability due to the specific focus on solar panel cleaning robots in Thailand. They may not apply to other technology adoption contexts. Based on these limitations, recommendations for future studies were made. First, future studies could consider conducting a more comprehensive study in various countries for comparison purposes, and second, cuts across more demographic segments and markets. Secondly, future researchers should consider conducting in-depth qualitative

research, such as interviews or focus groups, to explore the different factors affecting adoption deeper, providing richer insights and context for the identified recommendations.

8. Theoretical and Managerial Implications

Empowered by the shown data and evidence critical review of the literature sections, a set of recommendations was created in terms of managerial and theoretical implications. From the theoretical perspective, this research developed a theoretical model that could be adopted by stakeholders focusing on the solar panel cleaning robots in Thailand. The research developed the "Extended C-TAM-TPB", a theoretical model that extended the Combined Technology Acceptance Model - Theory of Planned Behavior (C-TAM-TPB)-the "Extended C-TAM-TPB" theoretical model comprising nine variables. Six variables attitude, subjective norm, perceived behaviour control, behavioural intention and perceived usefulness and of use to use were derived from C-TAM-TPB, while three variables were the extended one's trust in technology, awareness of renewable energy, and environmental concerns. These were included to represent the context of the study. Different variables were important to emphasize from the proposed theoretical model, as important towards solar panel cleaning robots' adoption. For the individual solar panel user, the variables considered important and directly influencing behavioural intention to use solar panel cleaning robots are the subjective norm, perceived behavioural control, trust in technology, and understanding of renewable energy. Though environmental concerns did not have a direct influence, they were considered to influence the individual users' attitude towards the use of cleaning robots.

For managerial implications, there are various aspects that managerial stakeholders such as policymakers, solar energy industry professionals, and researchers could consider. To enhance solar panel cleaning robots' adoption among individual users, this research recommends the following based on their significance level. Firstly, trust in solar panel cleaning robots' technology should be enhanced, using the inherent aspects such as perceived reliability, perceived privacy and security, reputation subjective norm, perceived behavioural control, trust in technology and y, and awareness of renewable energy. Secondly, the stakeholders should consider the subjective norm aspects, such as the influence that individuals perceive from important others, such as family, friends, colleagues, and experts. Perceived behavioural control was considered important regarding the self-efficacy of individual solar panel users, perceived resources and support, and the complexity of using solar panel cleaning robots. Awareness of renewable energy was considered critical in improving individuals, as it is important for users not only to be aware of the environmental benefits of using solar products but also to make them understand the wider implications for reducing the impact of global warming and ozone layer depletion. This research recommends that the stakeholders focus on improving their knowledge about renewable energy, environmental benefits, and familiarity with renewable energy.

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