International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2025, 15(4), 248-262.

The Mediating Role of Perceived Environmental Benefits in the Relationship between Perceived Environmental Concerns and Attitudes Toward Behaviors: The Case of Solar Photovoltaic Adoption in Indonesia

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Received: 25 January 2025 **Accepted:** 21 May 2025 **DOI:** https://doi.org/10.32479/ijeep.19399

ABSTRACT

This study explores psychological and behavioral pathways in pro-environmental behaviors. Given the mixed evidence on how environmental concerns influence solar PV adoption, this research examines the mediating role of perceived environmental benefits in shaping attitudes toward behavior. Employing a quantitative approach, survey data from 160 respondents were empirically assessed to delineate the interrelationships among perceived environmental concerns, perceived environmental benefits, and behavioral attitudes in the context of solar PV adoption in Indonesia. The results suggest that while attitudes toward behavior are influenced by perceived environmental concern, stronger impact occurs through the mediation of perceived environmental benefits. Although the direct effects are significant, they are comparatively weaker, suggesting that while value orientation and ethics serve as motivational factors, they are not the primary drivers of adoption. This study contributes to the discourse on solar PV adoption as part of a carbon neutrality strategy by highlighting the tangible benefits of an eco-friendly approach to renewable energy. Furthermore, it provides insights for policymakers to enhance communication strategies that improve public perception of environmental benefits, ultimately fostering greater acceptance of renewable technologies. Future research should further explore these relationships across diverse empirical contexts and integrate them into broader discussions on sustainability.

Keywords: Pro-environmental Behavior, Perceived Environmental Concern, Perceived Environmental Benefits, Attitude Toward Behaviors, Solar Photovoltaic Adoption
JEL Classification: Q42, Q50, Q54, M31

1. INTRODUCTION

As concerns about environmental sustainability and climate change rise, the global transition toward cleaner forms of energy has accelerated. Renewable energy development has become a must for governments, businesses, and individuals as fossil fuel consumption progressively continues to contribute to emissions (Manal, 2025).

One important pillar of this transition is the promotion of pro-environmental behaviors, which are a set of actions that lead to a more sustainable future for everyone. This is accompanied by rising regulatory pressures on fossil fuel industries, which cause energy firms to combine renewable sources into their operations and pursue multiple decarbonization strategies (Romasheva and Cherepovitsyna, 2023).

In response to these challenges, many countries have prioritized the shift to renewable energy, driven by concerns over climate change, energy security, and price volatility. Among various alternatives, solar power stands out as a key solution due to its sustainability and abundant availability (Shafie et al., 2022). Moreover, many governments around the globe have also enacted incentives and policies, like feed-in tariffs and subsidies, to promote renewable energy uptake and lead to a more sustainable energy system (Algarvio, 2023). In addition to policy support, foreign investment and green policies have played an essential role in enhancing the renewable energy mix, particularly in countries seeking to cultivate an equilibrium between industrial growth and ecological integrity (Agustina et al., 2023).

Despite these supportive measures, achieving a balanced and sustainable energy transition remains challenging, particularly in regions where financial limitations and policy constraints hinder large-scale renewable adoption. Nations with stricter environmental standards have emerged as leaders in the renewable energy sector, while others face economic pressures in their transitions towards sustainable energy sources (Faraji Abdolmaleki et al., 2023). However, most countries still face challenges to clean energy transitions due to limited access to finance and policy constraints (Adhikari et al., 2024). Furthermore, public acceptance of energy transition pathways and all the associated projects is extremely important, since large-scale adoption is usually impeded by resistance to change and lack of awareness (Ugwu et al., 2022).

Individual and collective pro-environmental behaviors that reduce energy consumption and adopt renewable energy technologies are critical for reducing climate change. Of these solutions, solar photovoltaic (PV) technology has proven to be a key enabler for an energy transition to carbon neutrality by providing renewable power generation. Wide adoption of solar PV is key to mitigating greenhouse gas emissions from conventional energy. However, pervasive integration simply cannot be achieved without addressing such financial and infrastructural constraint (Wattana and Aungyut, 2022) as well as psychological barriers including resistance to change, technological complexity, status quo bias, and uncertainty about market conditions (Huang and Cheng, 2023; Kyere et al., 2024; Zdonek et al., 2023).

Industrial-scale energy production and residential power consumption represent major anthropogenic catalysts of global carbon discharge. While solar PV technology presents a viable alternative, its adoption largely depends on financial and practical considerations. Although environmental concerns influence sustainability attitudes (Malik et al., 2020), studies indicate that individuals often prioritize economic incentives and other measurable benefits (Kyere et al., 2024; Scheller et al., 2024). Additionally, Huang and Cheng (2023) found that while ecological lifestyles and consumer innovativeness shape attitudes toward solar PV, financial constraints and policy incentives play a crucial role in adoption decisions.

This study examines how perceived environmental concerns influence attitudes toward solar PV adoption. Prior research presents mixed findings, with some studies suggesting that heightened environmental awareness drives investment in solar PV, while others indicate that financial incentives and infrastructural support are more influential.

Extant literature elucidates the significant impact of environmental consciousness in reinforcing favorable perceptions of technology adoption (Huang and Cheng, 2023; Kyere et al., 2024; Zdonek et al., 2023). However, other studies suggest that environmental concern does not have a significant role in driving PV adoption, because of lacking public understanding and insufficient government initiatives to get public awareness about the renewable energy benefits (Irfan et al., 2020; Shakeel and Rahman, 2018). This perspective is reinforced by Kesari et al. (2021), who found that environmental awareness is not a primary driver of household PV adoption, as consumers often doubt the effectiveness of individual actions in addressing global environmental challenges. Furthermore, research by Angowski et al. (2021) has noted that a high level of environmental concern may even reduce interest in PV adoption, as environmentally conscious consumers tend to consider long-term impacts rather than immediate practical benefits. Complementing these findings, studies also indicate that economic and technological constraints limit PV adoption, as highlighted by Aggarwal et al. (2020) and Irfan et al. (2020). Additionally, concerns regarding solar panel waste disposal, as discussed by Brown et al. (2021), add another layer of complexity to adoption decisions.

On the other hand, perceived environmental benefits still positively influence PV adoption intentions, even though they are often not the primary motivation compared to economic benefits (Aghlimoghadam et al., 2022; Scheller et al., 2024). Some studies, such as Corbett et al. (2022), show that perceived environmental benefits can strengthen adoption considerations. Moreover, research in different contexts also indicates that environmental concern enhances the perception of environmental benefits, as found in studies on green housing (Zhao and Chen, 2021) and sustainable travel behavior (Gelaidan et al., 2023). Studies in the green housing sector reveal the influence of environmental concern on perceived environmental benefits (Zhao and Chen, 2021).

Environmental concern not only leads to an increase in perceived green environmental benefits but also enhances perceived emotional and social benefits. This finding is likely since the environmental benefits of eco-friendly products are immediately visible to environmentally conscious individuals, allowing them to envision associated intangible benefits. Similarly, research on sustainable travel behavior has also found that environmental concern increases perceived environmental benefits (Gelaidan et al., 2023).

Furthermore, practical barriers to solar PV adoption remain significant despite growing awareness of renewable energy benefits. One of the main challenges is the high capital or investment cost at the beginning, associated with purchasing and installing solar PV systems (Arroyo and Carrete, 2019; Kyere et al., 2024; Mundaca and Samahita, 2020), insufficient government incentives (Wagner et al., 2024), and limited access to solar PV systems (Kapoor and Dwivedi, 2020; Kumar and Kaushik, 2022) continue to hinder widespread adoption.

While long-term savings on electricity bills may justify the investment, many individuals and businesses are deterred by the substantial initial capital required. In developing regions, where financial resources are often constrained, this cost burden becomes even more pronounced.

Limited access to financing options, such as green loans or government-backed subsidies, further exacerbates the issue, making solar energy less accessible to the general population (Arroyo and Carrete, 2019; Kyere et al., 2024; Mundaca and Samahita, 2020).

Additionally, insufficient government incentives hinder large-scale adoption (Wagner et al., 2024). While some governments have implemented tax breaks, feed-in tariffs, or subsidies to encourage the transition to solar energy, these measures are often inconsistent, inadequate, or difficult to access. Bureaucratic hurdles, policy uncertainty, and shifting regulatory frameworks create hesitation among potential adopters. Without strong institutional support, households and businesses may struggle to justify the investment in solar PV technology, particularly when cheaper but less sustainable alternatives remain readily available.

Moreover, limited access to solar PV systems due to geographical, infrastructural, and economic constraints presents another key obstacle (Kapoor and Dwivedi, 2020; Kumar and Kaushik, 2022). In rural or off-grid areas, the lack of distribution networks and skilled technicians are in the maintenance of the installation and maintenance efforts. Supply chain limitations and import dependency can drive up costs, making solar PV systems unaffordable for lower-income households. Even individuals with strong environmental concerns may hesitate to act if they do not perceive tangible benefits, such as long-term cost savings, energy independence, and carbon footprint reduction (Aggarwal et al., 2020; Irfan et al., 2020).

This study seeks to bridge this gap by analyzing how perceived environmental benefits function as key motivational drivers for fostering positive attitudes toward solar PV technology as well as examining the psychological and behavioral pathways that influence attitudes toward adopting solar PV technology. Specifically, it delineates the mediatory function of perceived environmental advantages in shaping the association between ecological concerns and pro-carbon-neutral attitudinal orientations. By addressing inconsistencies in prior research, this study pursues a more profound intellectual grasp on how environmental awareness translates into actionable attitudes when individuals recognize the practical and ecological advantages of solar PV.

Furthermore, this research endeavors to formulate policy recommendations and insights for industry practitioners, emphasizing the importance of effective communication strategies that highlight the environmental benefits of solar PV. By integrating psychological and behavioral theories, this study aspires to formulate a comprehensive framework for promoting solar PV adoption as a key driver of carbon neutrality. Ultimately, the findings will support policymakers, businesses, and advocacy groups in designing interventions that encourage widespread adoption of solar PV technology.

2. LITERATURE REVIEW

2.1. Perceived Environmental Concern (PENC)

Perceived environmental concern reflects a person's awareness and apprehension regarding environmental issues. It is often regarded as a key driver of pro-environmental attitudes, predominantly in the utilization of PV technology as a sustainable energy solution. However, the extent to which environmental concern directly influences adoption behavior remains debated.

Several studies suggest that heightened environmental concern positively influences solar PV adoption intentions (German et al., 2022; Huang and Cheng, 2023; Kyere et al., 2024; Lin et al., 2017; Mufidah et al., 2018; Zdonek et al., 2023). However, some researchers argue that this relationship is not always significant due to factors such as low public awareness, lack of financial incentives, and weak governmental policies supporting solar PV adoption (Irfan et al., 2020; Shakeel and Rahman, 2018).

Additionally, skepticism regarding individual contributions to global environmental challenges has been found to weaken the influence of environmental concern on adoption decisions (Kesari et al., 2021). Some consumers, despite being environmentally conscious, prioritize long-term economic considerations over immediate sustainability efforts (Aghlimoghadam et al., 2022; Angowski et al., 2021). Furthermore, economic and technological barriers, such as high installation costs and concerns about solar panel waste disposal, add further complexity to the transition from environmental awareness to adoption behavior (Brown et al., 2021; Scheller et al., 2024).

2.2. Perceived Environmental Benefits (PENB)

While the direct impact of environmental concern on adoption remains inconclusive, perceived environmental benefits play a more consistent role in influencing consumer decisions. Perceived environmental benefits refer to the tangible and psychological advantages associated with solar PV technology, such as reducing carbon emissions, improving energy efficiency, and contributing to environmental sustainability. Studies consistently demonstrate that individuals who recognize clear benefits coming from the environmental aspect are more likely to perform positive view toward solar PV adoption (Aghlimoghadam et al., 2022; Scheller et al., 2024).

Beyond its direct effect, perceived environmental benefits may also serve as a mediator between environmental concern and adoption behavior. Research suggests that individuals with strong environmental concerns tend to perceive greater environmental benefits from adopting sustainable technologies (Corbett et al., 2022; Zhao and Chen, 2021). For instance, studies on green housing and sustainable travel behavior indicate that perceived environmental benefits reinforce the relationship between environmental concern and behavioral intention (Gelaidan et al., 2023). This highlights the possibility that perceived benefits act as a crucial link, transforming environmental awareness into concrete pro-environmental actions, such as investing in solar PV technology.

2.3. Attitude Toward Behavior (ATB)

Attitude toward behavior refers to an individual's subjective evaluation of whether engaging in a specific action is desirable, beneficial, or effective. In the context of environmental sustainability, this behavior significantly influences individuals' propensity to embrace pro-environmental actions, including investment in solar PV technologies.

Within the framework of the Pro-Environmental Planned Behavior model, perceived environmental concern has been identified as a key antecedent shaping attitudes toward pro-environmental behavior (German et al., 2022; Lin et al., 2017; Mufidah et al., 2018). When individuals acknowledge the significance of environmental issues, they are more likely to evaluate pro-environmental actions positively, reinforcing their motivation to adopt sustainable technologies like solar PV. Research indicates that individuals with higher levels of environmental consciousness tend to form more favorable attitudes toward environmentally friendly technologies. As climate change concerns intensify and the need for sustainable energy solutions becomes more pressing, individuals with strong environmental values increasingly recognize solar PV technology as a practical and impactful solution. This awareness not only enhances their perception of its effectiveness in reducing carbon emissions but also fosters a sense of moral obligation to adopt it. Thus, higher perceived environmental concern serves as a psychological catalyst for the formation of pro-environmental attitudes and subsequently, the intention to act.

Nevertheless, the cultivation of a favorable disposition toward PV energy assimilation is not solely dependent on environmental concern. Perceived environmental benefits might also significantly shape individuals' attitudes and preparedness to allocate financial assets for PV technology integration (Aghlimoghadam et al., 2022; Scheller et al., 2024). This may imply that a mix of intrinsic motivation (concern for the environment) and extrinsic motivation (seen advantages to the environment) might play a significant effect in the formation of attitudes toward solar PV technology.

2.4. Willingness to Use Solar PV Technology (WTU)

The inclination toward solar PV adoption encapsulates an individual's deliberate intent and infrastructural preparedness for PV integration, contingent upon psychological and contextual determinants shaping its perceived viability and utility. One of the most prominent theoretical perspectives explaining this behavior is the Theory of Planned Behavior (Ajzen, 1991; 2012; Bosnjak et al., 2020; Madden et al., 1992). According to this theory, attitude plays a fundamental role in shaping behavioral intentions. A resolute affirmative disposition toward a behavior enhances willingness to act. Individuals who feel that solar PV technology is beneficial and aligned with their values tend to adopt it. Research consistently confirms that attitude toward behavior is a strong predictor of willingness to use solar PV technology, reinforcing the need for strategies that improve perceptions of its environmental and economic benefits.

2.5. Conceptual Framework

It is necessary to have a more in-depth knowledge of the psychological factors that motivate people to adopt sustainable habits to proceed with the transition toward carbon neutrality, especially the implementation of solar PV technology. One of the most important factors that determines the outcome of this process is the attitude toward behavior, which is a significant factor in determining how technology is adopted. Nevertheless, attitudes do not evolve in a vacuum; rather, they are impacted by perceived environmental problems as well as considered environmental advantages.

Perceived environmental concerns describe the knowledge and fear that a person has about environmental concerns, such as climate change and the sustainability of energy resource use. The findings of previous research indicate that this type of concerns has a favorable impact on attitudes toward activities that are focused on sustainability (German et al., 2022; Lin et al., 2017). However, previous research has produced inconsistent findings, such as practical barriers, competing priorities, and financial concerns that may weaken the direct impact of environmental concern on attitude formation (Irfan et al., 2020; Shakeel and Rahman, 2018).

To address this gap, this study introduces perceived environmental benefits as a mediator. This kind of benefit refers to the tangible and psychological advantages of solar PV technology on environmental aspects such as reduced emissions and improved efficiency. Recognizing these benefits strengthens the relationship between environmental concern and attitudes, as individuals who perceive greater benefits are more likely to develop favorable views toward solar PV technology (Aghlimoghadam et al., 2022; Corbett et al., 2022). On top of that, attitude is an essential component in determining whether a person is willing to embrace solar PV technology. Individuals who cultivate a positive disposition toward solar PV technology are predisposed to developing a heightened inclination to adopt it, as postulated by the Theory of Planned Behavior. This theoretical perspective suggests that attitudinal favorability acts as a crucial psychological antecedent, reinforcing one's volitional intent to integrate solar PV solutions into their energy consumption practices (Ajzen, 1991).

Accordingly, the subsequent hypotheses are meticulously delineated within the conceptual paradigm articulated in this scholarly inquiry (Figure 1). These hypotheses are predicated upon a theoretically rigorous foundation, offering a structured analytical lens through which the proposed relationships among variables are systematically examined:

H_1:"Perceived Environmental Concern positively influences Attitude Toward Behavior"

H_2:"Perceived Environmental Concern positively influences Perceived Environmental Benefit"

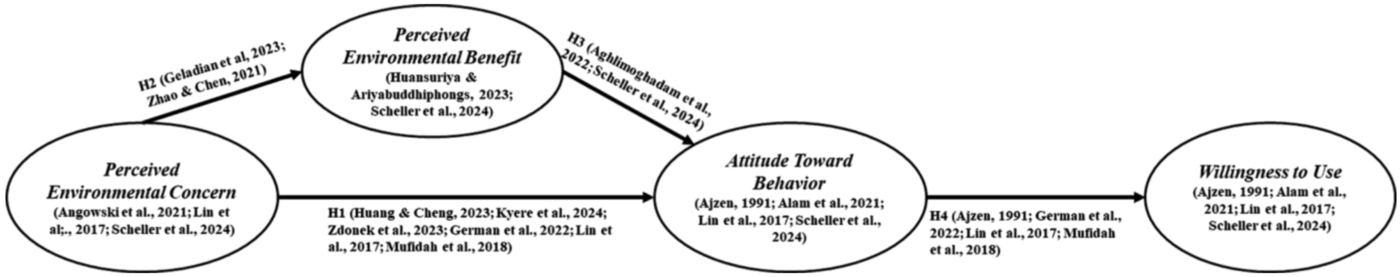
H_3:"Perceived Environmental Benefit positively influences Attitude Toward Behavior"

H_{3a}:"Perceived Environmental Benefit mediates the relationship between Perceived Environmental Concern and Attitude Toward Behavior"

H_4:"Attitude Toward Behavior positively influences Willingness to Use Solar PV Technology"

These hypotheses are underlined by theoretical frameworks from behavioural and environmental psychology, which help explain cognitive and evaluative processes of decision-making towards pro-environmental action. As a critical antecedent, perceived environmental concern relates to the awareness of an individual focusing on the consequences of his own behavior

Figure 1: Conceptual framework



through knowledge about ethical concerns toward environmental destruction.

The role of perceived environmental benefit as both a direct determinant of attitude as well as a mediating agent in the environmental concern-attitude paradigm will elucidate additional insight into the manner in which individuals navigate the justifications for engaging in solar PV technology. This multi-level model recognizes that people may react not just to high level environmental issues but also weigh specific positive consequences before developing positive attitudes to adoption.

This study would also enrich the wider discussion on sustainable technology adoption as it sheds light on the psychological antecedents which drive behavioural change by clarifying these relationships. Such findings can aid in crafting specific campaigns designed to utilize environmental concern and promote the right message of solar as "good for you," thus guiding attitudes, and in the end push for greater adoption of solar energy.

By unearthing these psychological barriers to solar PV adoption, this research provides a pathway for governments and industry stakeholders to develop persuasive messaging, optimize incentive structures, and build trust in solar PV technology, ultimately aiding in the imperative transition to renewable energy sources. Thus, this research offers an evidence-based perspective to promote sustainability initiatives at both the policy level and the market level.

3. RESEARCH METHODOLOGY

For the purpose of examining the links between perceived environmental concern, perceived environmental benefits, attitude toward behavior, and willingness to use solar PV technology, this study used a quantitative research technique. According to Creswell and Creswell (2018), the deployment of quantitative methodologies is contingent upon their intrinsic ability to yield objective, empirically measurable data amenable to rigorous statistical interrogation. This methodological rigor facilitates the extrapolation of research findings to a more extensive demographic, thereby fortifying the external validity of the study. Consequently, the adoption of this empirical paradigm ensures the methodological robustness, replicability, and epistemic reliability of the derived conclusions, ultimately advancing a more nuanced and holistic comprehension of the diffusion and operational integration of solar PV technology.

A hypothesis-driven analytical framework is employed to systematically assess both direct and mediated effects, with particular emphasis on the intermediary role of perceived environmental benefits in the nexus between perceived environmental concern and attitudinal orientation toward behavior.

To interrogate these interrelationships, the Partial Least Squares Structural Equation Modeling (PLS-SEM) technique is utilized, leveraging its variance-based computational framework. This methodological approach was specifically designed to address inherent limitations associated with Covariance-Based Structural Equation Modeling (CB-SEM), particularly in managing constrained sample sizes and accommodating abnormal data distributions (Chin, 1998; Hair et al., 2014). In contrast to CB-SEM, which utilizes covariance matrices to assess model fit and is more suitable for theory confirmation (Byrne, 2010; Hair et al., 2011), PLS-SEM prioritizes the optimization of the explained variance within endogenous constructs, rendering it particularly advantageous for predictive analytics and the iterative refinement of theoretical paradigms. Its algorithmic architecture is inherently designed to enhance model robustness in exploratory research settings, facilitating the identification of latent structural relationships and advancing the empirical validation of emergent theoretical frameworks (Hair et al., 2011).

PLS-SEM integrates confirmatory factor analysis with path analysis, thereby enabling researchers to construct and evaluate intricate theoretical models encompassing multiple independent and dependent variables (Chin, 1998). This adaptability renders it a suitable selection for research endeavors that aspire to explore nascent theoretical relationships, such as the adoption of sustainable technologies. Furthermore, PLS-SEM's ability to function with relatively small sample sizes and its exemption from multivariate normality requirements make it a particularly advantageous tool in studies grappling with data constraints or those that are in the process of theoretical model development (Hair et al., 2014).

The present study has been meticulously designed to offer insights into the psychological and behavioral factors that influence sustainable decision-making in the fuel retail industry. Employing structural equation modeling, the research evaluates the influence of environmental concern on attitudes toward sustainability and the subsequent effect on the adoption of carbon-neutral technologies, particularly solar PV technology. The study incorporates control variables to ensure a comprehensive analysis of factors that may impact adoption behavior.

3.1. Sample and Data Collection

To validate the proposed model, data was collected from 160 respondents consisting of Indonesian managers and owners of retail fuel businesses. These participants were purposefully identified based on their central role in the coordination of energy distribution networks and their tactical agency in devising sustainability-focused policies and measures Theirs is a considerable know-how in terms of decision-making power and sectoral expertise, making them key stakeholders in the design and implementation of renewables transitions. This study focuses on the integration of renewable energy solutions like solar-powered fuel stations into the fuel retail sector to help achieve the national target of carbon reduction.

The data was collected using a highly standardised questionnaire and administered according to detailed methodological procedures to ensure standardisation of input from respondents. This was a specific purpose-built tool intended to produce specific, measurable insights and, through the reduction of bias in answers, aimed to improve data collected in terms of reliability and validity (Table 1), delivered and distributed through multiple web channels. Respondents who had decision-making authority over investment in petroleum retail operations were selected through purposive sampling. In order to ensure that the findings of the study are correct and appropriate. Such a focused method guarantees realistic responses as both interest and saturation are taken into consideration of the adoption of solar PV technology while in turn increasهني the relevance and validity of the research.

The questionnaire was thoroughly pre-tested with a small subset of respondents before the full-scale data collection started. This initial assessment was performed to evaluate the clarity, contextual relevance, and cognitive accessibility of the instrument. Feedback from this pilot assessment informed the refinements in wording of survey items to achieve better linguistic precision and semantic coherence.

3.2. Measurement Tools

In accordance with the principles of validity and reliability, the present study utilizes measurement scales that have been previously validated and adapted from prior research. A structured five-point Likert scale, spanning from "strongly disagree" to "strongly agree," was systematically implemented to quantify each construct, ensuring uniform interpretability of participant responses. The deployment of an odd-numbered scaling framework, incorporating a central midpoint to accommodate neutral perspectives, has been empirically validated as an effective mechanism for capturing ambivalent or indifferent dispositions. This methodological approach enhances response granularity while mitigating potential distortions arising from forced-choice limitations (Chyung et al., 2017) and potentially enhances the reliability of the instrument (Adelson and McCoach, 2010). This methodological approach ensures that the measurement accurately captures the full range of respondents' attitudes while maintaining the robustness of the data.

This study employs a structured questionnaire to measure four key constructs: Perceived Environmental Concern (PENC), Perceived Environmental Benefit (PENB), Attitude Toward Behavior (ATB), and Willingness to Use Solar PV Technology (WTU). Each variable is assessed using validated items adapted from previous research to ensure reliability and accuracy in capturing respondents' perceptions and behavioral intentions regarding technology adoption.

Perceived Environmental Concern (PENC) is measured through items assessing an individual's awareness of environmental issues, concern about climate change, and the perceived urgency to act sustainably. This construct reflects how much individuals recognize the risks posed by environmental degradation and whether these concerns translate into a proactive mindset toward sustainability. The items in this study are adapted from Angowski et al. (2021), Lin et al. (2017), and Lin et al. (2017), focusing on

Table 1: Questionnaire design

Items	Questions	References
PENC1	*"I am worried about current environmental issues"*	Angowski et al. (2021), Lin et al. (2017), and Lin et al. (2017)
PENC2	*"I am worried that environmental problems may worsen in the future"*	
PENC3	*"I am worried about human actions that show a lack of concern for the environment"*	
PENC4	*"I feel that current environmental problems will not get worse in the near future if no action is taken"*	
PENB1	*"I feel that installing a solar photovoltaic system in my business unit will help environmental conservation efforts"*	Huansuriya and Ariyabuddhiphongs (2023) and Scheller et al. (2024)
PENB2	*"I feel that installing a solar photovoltaic system in my business unit gives me the feeling that I have done something beneficial for the environment"*	
PENB3	*"I feel that installing a solar photovoltaic system in my business unit will show my concern for the environment"*	
PENB4	*"I feel that installing a solar photovoltaic system in my business unit will not provide any environmental benefits"*	
ATB1	*"I like the idea of using solar photovoltaic technology in my business unit"*	Ajzen (1991), Alam et al. (2021), Lin et al. (2017), and Scheller et al. (2024)
ATB2	*"I feel happy about the installation of solar photovoltaic technology in my business unit"*	
ATB3	*"I feel that installing solar photovoltaic technology in my business unit is a good idea"*	
ATB4	*"I feel that participating in the plan to use a solar photovoltaic system in my business unit is an unwise decision"*	
WTU1	*"I will strive to implement a solar photovoltaic system in my business unit"*	Ajzen (1991), Alam et al. (2021), Lin et al. (2017), and Scheller et al. (2024)
WTU2	*"I will strive to purchase or lease a solar photovoltaic system for my business unit"*	
WTU3	*"I will install a solar photovoltaic system in my business unit as soon as possible"*	
WTU4	*"I am not interested in immediately using a solar photovoltaic system in my business unit"*	

the degree of worry about both current and future environmental conditions. To operationalize this construct, four key items capture different dimensions of environmental concern. The first item assesses general worry about environmental problems, measured by the statement *"I am worried about current environmental issues"* (PENC1). The second item evaluates concerns about the worsening state of the environment in the future, as reflected in *"I am worried that environmental problems may worsen in the future"* (PENC2). The third item focuses on the perceived negative impact of human activities on the environment, captured through *"I am worried about human actions that show a lack of concern for the environment"* (PENC3). To balance the construct, a reverse-coded item is included to measure a more indifferent perspective, reflected in *"I feel that current environmental problems will not get worse in the near future if no action is taken"* (PENC4, R).

Perceived Environmental Benefit (PENB) is evaluated through statements measuring the advantages individuals associate with adopting solar PV technologies as part of their carbon-neutral initiatives. This construct assesses whether respondents perceive sustainable solutions, such as solar PV systems, as beneficial in reducing carbon emissions, improving energy efficiency, and providing other environmental benefits. The measurement items are adapted from Huansuriya and Ariyabuddhiphongs (2023) and Scheller et al. (2024), emphasizing both the tangible and psychological benefits of these carbon-neutral practices. To operationalize this construct, four key items are included to capture respondents' perceptions of solar PV technology's environmental impact. The first item measures the belief that adopting solar PV contributes to environmental preservation, as reflected in the statement *"I feel that installing a solar PV system in my business unit will help environmental conservation efforts"* (PENB1). The second item assesses the emotional satisfaction derived from engaging in environmentally beneficial actions, captured through *"I feel that installing a solar PV system in my business unit gives me the feeling that I have done something beneficial for the environment"* (PENB2). The third item reflects the perception that adopting renewable energy technologies demonstrates personal and corporate environmental responsibility, measured by *"I feel that installing a solar PV system in my business unit will show my concern for the environment"* (PENB3). To balance the construct, a reverse-coded item is included to capture skepticism regarding environmental benefits, measured by *"I feel that installing a solar PV system in my business unit will not provide any environmental benefits"* (PENB4, R).

Attitude Toward Behavior (ATB) is measured through respondents' positive or negative perceptions of engaging in sustainable practices. This construct captures both the affective (emotional) and cognitive (rational) dimensions of attitudes toward adopting carbon-neutral technology, particularly the adoption of solar PV technology. Items are adapted from Ajzen (1991), Alam et al. (2021), Lin et al. (2017), and Scheller et al. (2024), capturing essential attitudinal factors toward the adoption of solar PV technology. The first item assesses the general preference for carbon-neutral solutions, measured by the statement *"I like the idea of using solar PV technology in my business unit"* (ATB1). The second item reflects emotional responses to adopting sustainability measures, expressed through *"I feel happy about the installation of solar PV technology in my business unit"* (ATB2). The third item evaluates the perceived feasibility and rational assessment of transitioning to renewable energy sources, measured by *"I feel that installing solar PV technology in my business unit is a good idea"* (ATB3). Additionally, a reverse-coded item is included to assess potential skepticism or reluctance toward adoption, measured by *"I feel that participating in the plan to use a solar PV system in my business unit is an unwise decision"* (ATB4, R).

Willingness to Use Solar PV Technology (WTU) is assessed by measuring respondents' self-reported likelihood of investing in, implementing, or supporting solar PV as carbon-neutral solutions in their businesses. This construct is adapted from Ajzen (1991), Alam et al. (2021), Lin et al. (2017), and Scheller et al. (2024), which suggests that behavioral intention is a key predictor of actual behavior. The measurement includes indicators which emphasize that behavioral intention serves as a key predictor of actual behavior. Four key items are included to capture different aspects of willingness to adopt solar PV technology. The first item assesses respondents' proactive efforts to implement solar PV systems, measured by the statement *"I will strive to implement a solar PV system in my business unit"* (WTU1). The second item evaluates their commitment to financial investment or leasing, reflected in *"I will strive to purchase or lease a solar PV system for my business unit" (WTU2).* The third item measures the immediacy of their adoption plans, captured through *"I will install a solar PV system in my business unit as soon as possible"* (WTU3). Additionally, a reverse-coded item is included to detect reluctance or lack of urgency in adoption, measured by *"I am not interested in immediately using a solar PV system in my business unit"* (WTU4, R).

By using validated scales and adapting items from well-established studies, this research ensures that the key constructs are measured with high validity and reliability. The structured questionnaire provides a comprehensive assessment of how environmental concern, perceived benefits, attitudes, and willingness to use carbon-neutral technology interact in shaping sustainable business decisions.

These evaluative forms constitute the foundational framework for systematically examining both direct and mediated relationships within the study's conceptual model, thereby elucidating the psychological and behavioral determinants underpinning sustainability adoption within Indonesia's fuel retail sector. Prior to the final deployment of the measurement instrument, each scale underwent rigorous psychometric validation, including assessments of internal consistency, reliability, and construct validity, ensuring methodological robustness and empirical precision in capturing latent constructs.

3.3. Data Analysis Approach

Based on the methodology proposed by Hair et al., the analysis utilizes a systematic two-step approach of PLS SEM, which helps in identifying and measuring relationships in a conceptual framework (Hair et al., 2017).

The initial step is to evaluate a measure framework for the determination of construct validity and reliability. Factor loadings represent the main evaluation metrics to determine the reliability of individual indicators. Values above 0.7 for these indicate the good level of representational fidelity of the indicators. This happens through the application of factor loadings.

In order to test the internal consistency of the measurement model, a critical evaluation, Cronbach's Alpha (CA), and Composite Reliability (CR) tests were conducted, with an expectation that both statistics will exceed the 0.7 threshold. In this way, the indicators stay sufficiently aligned. The establishment of convergent validity implies the Average Variance Extracted (AVE) should exceed 0.50 such that it travels a greater fraction of variance on its respective indicators.

In addition, in order to validate the empirical uniqueness of a construct, it is essential to validate its discriminant validity. Various evaluative techniques carry out this verification process. First, cross-loadings should demonstrate that an indicator exhibits a stronger relationship with its intended construct than with any foreign construct. Second, according to Fornell and Larcker, the square root of a construct's AVE should be greater than the inter-correlations shared with other constructs. Finally, the Heterotrait-Monotrait (HTMT) ratio should be less than the threshold of 0.9 in order to avoid excessive collinearity. Problems in creating surveys and issues in measuring latent variables can serve to artificially inflate correlations between constructs, hiding the divide between separate components of theory.

Building upon the reliability and validity assessments, in the second stage, structural model assessment focuses on relationships among constructs using path coefficients (β) and P-values. Hypotheses are tested, t-statistics and P-values are calculated, with significance levels set at 0.05 (5%) to determine statistical significance. The coefficient of determination (R^2) is also measured to quantifie how independent factors explain the dependent variable. Generally, R^2 values above 0.75 indicate a strong explanatory power, values between 0.50 and 0.75 suggest a moderate effect, while values between 0.25 and 0.50 indicate a weak effect, and values below 0.25 reflect minimal explanatory power. To further refine the model's explanatory power, effect size (f^2) (Cohen, 1988; Hair et al., 2017) complements R^2, and can be defined as a small (0.02), medium (0.15), or large effect (0.35), providing more insight into the significance of each independent variable.

Beyond explanatory power, Standardized Root Mean Square (SRMR) is used for a more rigorous assessment of fitness. SRMR values below 0.1 are acceptable, and values below 0.08 are considered optimal (Hair et al., 2017; Henseler et al., 2016). Lower SRMR score indicates lower probability of specification mistakes.

Predictive relevance is also assessed using Q^2, a blindfolding-based criterion that evaluates the model's ability to predict data points not included in the estimation. When Q^2 is >0, we consider that the model can be used with new input data that was not used in the sample and still make good predictions. Following this, PLS Predict is conducted to evaluate the model's out-of-sample predictive capabilities, further strengthening the assessment of its practical applicability (Hair et al., 2019; Shmueli et al., 2019).

To interpret the result, we will be looking at the path coefficients, their significance as well as the predictive strength of the model. Theoretical assumptions and the conceptual framework tested in the study validation are also supported by the relationships that are significant and help explain the data.

Following this two-step process allows researchers to thoroughly evaluate both the measurement model and the structural model in a systematic and rigorous way. This self-imposed methodological rigor leads to increased credibility of the findings, as well as increased confidence in the relationships between variables, and results in a strong theoretical and practical contribution.

4. RESULTS

4.1. Pre-Test Results

To assure the methodology rigor and the measurement instrument precision, a pre-test was performed through statistical software. The purpose of this preliminary evaluation was to assist in the determination of content validity for the questionnaire items and assess the reliability of the items before a full-scale survey was deployed. The methodological precaution of the pre-test will help us to discover any shortcomings with our set of inventory questions, such as semantic vagueness, redundancy of items or any inconsistency in measuring our constructs. Thus, by honing the tool in concert with findings from the pretest, researchers can tangibly augment the strength, accuracy, and validity of the data collection process, handsomely increasing the empirical backbone of the study.

The validity test was performed using the Pearson correlation analysis to assess the relationship between each item in the questionnaire with each construct. The validity test was performed using the Pearson correlation analysis to assess the relationship between each item in the questionnaire with each construct. Results showed that all items had acceptable $P < 0.05$ (Table 2) indicating that all items are statistically valid and each item in the development process represents the intended construct. That is, the items in the questionnaire reflected what they were supposed to (supporting their Theoretical validity). While validity must be established from the beginning, items proven to be invalid can erode the integrity of the resulting findings, leading to measurement error and misguided results.

A diagnostic reliability assessment was executed to ensure the internal homogeneity of the measurement instrument. For this purpose, the cronbach's alpha was used as the main reliability measure. All constructs in this study had coefficient values exceeding the recommended 0.7 (Table 3), which signals that the items of the questionnaire are internally correlated and will thus actually measure for the latent constructs they were meant to measure. This methodological rigor increases the replicability and stability of the collected responses and reduces the potential for stochastic measurement errors. In social science research, for instance, constructs are generally operationalized via multi-item scales to ensure adequate representation of the construct and measurement precision, making high reliability particularly salient.

4.2. Data Collection Results and Descriptive Analysis of Respondent

Under the data gathering phase, an online survey was conducted through the support of Google Form. The survey was elaborated to the managers and owners of gasoline station in Indonesia. The survey was available to those directly responsible for strategic and operational decision-making processes from December 2024 to January 2025, thereby enabling the analysis and mediation of the policy-setting and execution process by the highest-ranking officials.

On the back of the opt-in, conversations were naturally integrated into the discussions at hand, increasing authentic observation of respondents in their comments contributed. At the end of the survey, we received 185 responses from various regions in Indonesia. Those people were in all sorts of places. A diverse demographic representation of attendees provided a comprehensive perspective on the business applications of PV technology. As a result of the data cleaning procedure, 25 replies were deemed invalid due to issues like straight-lining (22 cases) and inconsistencies in reverse-coded questions (3 cases). To resolve that matter, these replies were deleted; as a result, a final dataset included 160 valid responses for exploration. Adding reverse coded items was a useful addition as it strengthens data quality by identifying careless or inattentive responses. This methodological antidote did wonders in enhancing the overall reliability of our dataset, minimizing response bias, and bringing about greater accuracy in the underlying constructs.

Demographic profiling was also conducted through descriptive analysis to gain deeper insights into respondent attributes, including gender, age, educational background, and professional experience. The dataset included regional distribution as well, which indicated the geographical diversity of the respondents. The predominantly male character of the business is reflected in the fact that the great majority of 160 valid respondents were male. Most responders were between 30 and 50 years old, which means the workforce is not fresh and still has some experience.

To this end, the background on education shows that the majority of participants had their senior years of high school, while a notable fraction of them had higher education degrees (e.g. bachelor's). The levels of work experience were quite varied among these responses, with many of the respondents showing a very high degree of mastery of the industry. This range of knowledge ensured a higher reliability of responses associated with PV take-up, as it represented a cross-section of industry experience and formal academic subject matter expertise. In particular, both types of individuals were represented in the responses.

This regional distribution study results showed that the answer spread in the very superior areas in Indonesia. This broad account enabled a comprehensive understanding of the regional differences with respect to the adoption of PV technology.

Table 2: Pre-test results 1 (instrument validity)

Item	Significance	Item	Significance
PENB1	0.002	ATB1	0.000
PENB2	0.001	ATB2	0.000
PENB3	0.000	ATB3	0.000
PENB4	0.000	ATB4	0.000
PENC1	0.000	WTU1	0.000
PENC2	0.002	WTU2	0.000
PENC3	0.000	WTU3	0.000
PENC4	0.000	WTU4	0.000

Source: Statistical Software Output (2025)

Table 3: Pre-test result 2 (instrument reliability)

Cronbach's Alpha	No. of Items
0.949	16

Source: Statistical Software Output (2025)

4.3. PLS-SEM – Measurement Model Assessment

The measurement model underwent a rigorous evaluation of its psychometric reliability and construct validity to refine construct measurement. This criterion, therefore, is valuable in guaranteeing that the measurement items accurately embody the theoretical constructs they aim to measure.

To establish a solid foundation before assessing validity and reliability, we first examined the mean, standard deviation, and item-factor loadings to validate the data distribution and assess the strength of the relationships between items and their respective constructs (Table 4). This preliminary step is crucial in establishing the representativeness and consistency of measurement items, providing deeper insights into response patterns and the robustness of indicators.

The mean scores for all constructs range between 3.15 and 3.69, suggesting moderately positive responses across the items. Standard deviations (SD) range from 0.84 to 1.13, reflecting a moderate level of variability in responses. Among the factors, PENC3 (M = 3.69, SD = 1.06) had the highest mean, indicating a relatively stronger agreement, while WTU3 (M = 3.15, SD = 0.92) had the lowest, suggesting weaker agreement. The variability in responses is slightly higher in the PENC factor, as seen in PENC4 (SD = 1.13), indicating greater dispersion in perceptions compared to other factors. Furthermore, factor loadings (FL) across all items exceeded the recommended threshold of 0.70, demonstrating strong indicator reliability. Most items had FL values above 0.90, reinforcing their contribution to the respective constructs.

Reliability diagnostics affirmed the model's internal consistency, with CA and CR exceeding the conventional 0.7 benchmark (Table 4). This confirms that the constructs are well-defined and yield consistent and repeatable results. Furthermore, an analysis of construct validity reinforces the robustness of the measurement framework. An Average Variance Extracted (AVE) value above 0.50 confirms that the measurement scale aligns with the theoretical background, fulfilling the requirements of convergent validity. These results also strengthen the theoretical and practical reliability of the measurement model.

Beyond reliability and convergent validity, an assessment of discriminant validity further strengthens the model's credibility.

Table 4: Respondent's descriptive and reliability statistics

Factor	Item	Mean	SD	FL	CA	CR	AVE
ATB	ATB1	3.39	0.87	0.931	0.926	0.926	0.819
	ATB2	3.31	0.84	0.921			
	ATB3	3.48	0.94	0.930			
	ATB4	3.48	0.86	0.836			
PENB	PENB1	3.65	0.92	0.925	0.915	0.917	0.797
	PENB2	3.56	0.91	0.868			
	PENB3	3.56	0.85	0.930			
	PENB4	3.58	0.88	0.846			
PENC	PENC1	3.51	1.02	0.924	0.907	0.912	0.785
	PENC2	3.54	1.07	0.928			
	PENC3	3.69	1.06	0.910			
	PENC4	3.36	1.13	0.773			
WTU	WTU1	3.32	0.93	0.926	0.936	0.938	0.840
	WTU2	3.21	0.88	0.916			
	WTU3	3.15	0.92	0.936			
	WTU4	3.26	0.91	0.887			

Source: PLS SEM Output (2025)

The HTMT scores were below the 0.90 threshold (Table 5), confirming empirical construct discrimination. Furthermore, the square root of each construct's AVE (Fornell-Larcker Criterion) exceeded its correlations with other constructs (Table 6), ensuring that no constructs are substantially similar.

The series of diagnostic tests confirm the reliability and construct validity of our measurement framework by demonstrating the internal consistency of the constructs, the conceptual distinctiveness of factors, and the systematic discriminability of constructs within the model.

Overall, the measurement model evaluation results based on all the messurement models are statistically satisfactory, internally consistent, and theoretically meaningful, thus providing further qualification for structural model evaluation.

4.4. PLS-SEM – Structural Model Evaluation

The structural model was analyzed to assess the hypothesized relationships among the constructs. This evaluation supports the theoretical foundation, providing empirical evidence for indicating the link direction and strength between variables. Route analysis was used to estimate the structural model and to test the relative predictive power of our computed factors over solar PV technology uptake. As shown in Figure 2, the results were significant, confirming the theoretical framework proposed earlier and strengthening the predictive validity of the model for solar PV usage intention.

The result substantiates a robust and positive causal relationship between ATB and WTU (β = 0.795, P < 0.001), indicating that having a positive attitude fosters an intention to adopt. Furthermore, PENC has a strong positive impact on PENB (β = 0.815, P < 0.001) and a strong influence on ATB (β = 0.630, P < 0.001). In a further test of the hypothesis (Table 7), this finding supports these relationships as confirmed, with PENC being directly related to ATB (H1: β = 0.218, t = 2.683, P < 0.01), though to a lesser extent than expected. Similar to H1, there is also a significant relationship between PENC and PENB (H2: β = 0.815, t = 25.320, P < 0.001), which is much stronger, however, than the first, showing that respondents who reported greater environmental concern also believe that they receive more environmental benefits by practicing sustainable behaviors. H3 further validates the mediating role of PENB, as it shows significance toward ATB (β = 0.630, t = 8.037, P < 0.001). The effects of perceived benefits on ATB (H3b: β = 0.348, t = 5.257, P < 0.001)(M1) indicate that respectively much of the PENC's influence on ATB occurs via perceived benefits predictably supporting mediation analysis (H3a: β = 0.514, t = 7.712, P < 0.001) suggesting that cognitive appraisals play a key role in determining attitudes toward the adoption of sustainable technology.

Table 5: Heterotrait monotrait (HTMT) ratio

	ATB	PENB	PENC
ATB			
PENB	0.877		
PENC	0.799	0.897	
WTU	0.853	0.815	0.765

Source: PLS SEM Output (2025)

Table 6: Fornell Larcker criterion

	ATB	PENB	PENC	WTU
ATB	0.905			
PENB	0.808	0.893		
PENC	0.731	0.815	0.886	
WTU	0.795	0.755	0.704	0.916

Source: PLS SEM Output (2025)

Moreover, the mediation model undoubtedly concludes that PENC has a significant positive indirect effect on WTU through PENB and ATB (β = 0.408, P < 0.001), which empirically indicates the cascading impact of environmental concern on adoption behavior. As the very last postulated hypothesis (H4), ATB is revealed to be a significant antecedent of WTU (β = 0.795, t = 20.507, P < 0.001), once again confirming that positive attitudes are a fundamental arrival at a willingness to install solar PV technology. Taken together, these findings emphasize both direct and indirect pathways by which individuals' environmental consciousness, perceived benefits, attitudes, and behavioral intentions drive widespread appeal of sustainable technology.

Figure 2: Estimated path coefficients of the research model. Statistical significance is indicated using asterisks (*P < 0.050, **P < 0.010, ***P < 0.001)

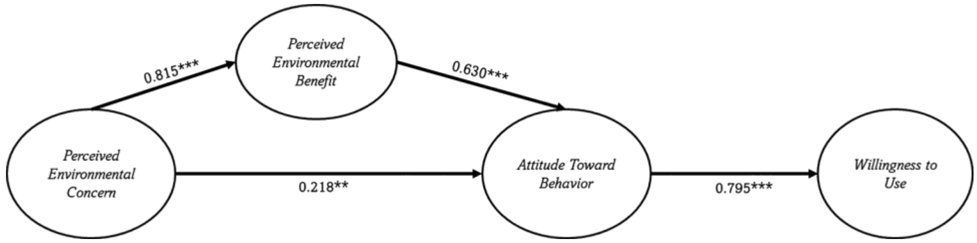


Table 7: Hypothesis testing results

Hypothesis	Path Coeff	T Statistic	Sig	Results
H_1: PENC -> ATB	0.218	2.683	0.004	Accepted
H_2: PENC -> PENB	0.815	25.320	0.000	Accepted
H_3: PENB -> ATB	0.630	8.037	0.000	Accepted
H_{3a}: PENC -> PENB -> ATB	0.514	7.712	0.000	Accepted
H_4: ATB -> WTU	0.795	20.507	0.000	Accepted

Source: PLS SEM Output (2025)

To further validate structural relationships, R-squared values were examined to determine the explanatory power of independent variables on the dependent variables. The results (Table 8) indicated that ATB (0.668), PENB (0.665), and WTU (0.632) accounted for a substantial proportion of variance, highlighting the model's predictive strength. Apart from explanatory power, effect size (f^2) analysis (Table 9) provided further insights into the strength of predictor variables. PENC exhibited a large effect on PENB (f^2 = 1.981), while ATB had a strong influence on WTU (f^2 = 1.715), emphasizing their critical roles in explaining behavioral intentions within the model.

4.5. Model Fit Assessment

Evaluating the robustness of the structural model, the SRMR was considered. Table 10 shows a good model fit for saturated model (0.047) and for estimated model (0.066), which confirmed that the hypothesised relationships were adequate in representing observed data. In addition, the value of NFI was found to be acceptable at 0.899, which also approached the acceptable threshold of 0.90.

4.6. Predictive Relevance Assessment

While model fit assessments confirm the adequacy of a structural model, they do not determine its practical utility. Instead, predictive relevance assessments ensure that the model is useful and capable of accurately predicting values. The Q^2 values (ATB = 0.540, PENB = 0.522, WTU = 0.526) indicate strong predictive capability, reinforcing the model's applicability in forecasting behavioral outcomes (Table 11).

Furthermore, the PLS-Predict test revealed that most values were consistently lower than those in Linear Modeling (Table 12), suggesting that our model outperforms linear models in predicting average observations. Additionally, all Q^2predict values were positive, further supporting the model's predictive validity.

PLS-SEM analysis results provide robust empirical confirmation for the significant relationships proposed by the theoretical framework that stimulates solar PV technology adoption. The high predictive accuracy of the model also adds to its practical significance, highlighting it as a useful tool for forecasting future trends.

Table 8: R-square

Variable	R-square	R-square Adjusted
ATB	0.668	0.664
PENB	0.665	0.662
WTU	0.632	0.629

Source: PLS SEM Output (2025)

Table 9: F-square

	ATB	PENB	PENC	WTU
ATB				1.715
PENB	0.401			
PENC	0.048	1.981		

Source: PLS SEM Output (2025)

Table 10: Model fit

	Saturated model	Estimated model
SRMR	0.047	0.066
NFI	0.899	0.894

Source: PLS SEM Output (2025)

Table 11: Predictive relevance

Variable	SSO	SSE	Q2(=1−SSE/SSO)
ATB	640.000	294.369	0.540
PENB	640.000	305.682	0.522
WTU	640.000	303.291	0.526

Source: PLS SEM Output (2025)

5. DISCUSSION

The empirical findings highlight the crucial role that PENC plays as a primary predictor of pro-environmental behaviour. These findings are in accordance with earlier studies (German et al., 2022; Huang and Cheng, 2023; Kyere et al., 2024; Lin et al., 2017; Mufidah et al., 2018; Zdonek et al., 2023) that highlighted how ecological awareness contributes positively to the uptake of solar PV technology. Yet although PENC and ATB had a statistically substantive direct relationship, PENB exhibited a stronger mediatory effect. This indicates that the benefits associated with environmental stewardship reinforce the favourable attitude towards environmental involvement, which in turn strengthens the behavioural propensity for environmentally responsible behaviour.

Beyond environmental concern, PENB serve as a pivotal cognitive determinant in cultivating affirmative attitudinal orientations toward the adoption of solar PV technology. The psychological salience of these perceived advantages enhances individuals' intrinsic motivation to engage with renewable energy solutions, reinforcing the perceived utility and long-term sustainability of solar PV systems. By functioning as a mediating construct, PENB not only amplifies pro-environmental predispositions but also strengthens the cognitive-behavioral nexus that underpins decision-making in sustainability transitions. Individuals who strongly believe that installing solar PV technology directly contributes to environmental conservation are more likely to perceive it as a meaningful action. Moreover, those who derive emotional satisfaction from engaged in sustainable behaviors develop stronger pro-environmental attitudes. Such perceptions are reinforced by the idea that solar PV is a kind of personal or corporate environmental responsibility policy, and that going solar aligns with those actional statements committing to sustainability.

This aligns with research showing that perceived benefits are a significant antecedent in translating environmental concern into actual pro-environmental behaviours (e.g., solar PV technology purchase) (Aghlimoghadam et al., 2022; Corbett et al., 2022; Gelaidan et al., 2023; Zhao and Chen, 2021). This inference indicates that while ecological consciousness may serve as a foundational factor in the generation of positive dispositions towards solar PV technology, a more decisive influence comes from the cognitive appraisal of concrete environmental benefits, like reduced carbon emissions and heightened contributions to sustainability. This indicates that individuals are more inclined toward solar PV adoption when they perceive direct, measurable ecological gains rather than relying solely on abstract environmental awareness.

Consequently, a campaign that highlights the immediate environmental benefits of carbon neutrality and PV technology may be an appropriate approach to create positive attitude. This assertion is rooted in empirical studies which show that those who see clear environmental benefits are more inclined to develop positive attitudes to the uptake of solar PV technology. These results suggest that the perceptual prominence of positive real-world impact precipitates pro-adoption attitudes and thereby supports the role of perceived benefits in facilitating sustainable choices (Aghlimoghadam et al., 2022; Scheller et al., 2024).

Perceived environmental benefits are therefore the main mechanism by which this influence takes place. This effect is consistent with prior academic research that demonstrates the cognitive appraisal of benefits as an underlying mechanism that connects environmental concern and behavior intention. This highlights the critically important role of perceived advantages in transforming environmental sensitivity into behavioral intents, confirming the facilitatory effect of benefit-oriented incentive mechanisms in sustainable decision processes (Gelaidan et al., 2023; Zhao and Chen, 2021). Individuals would exhibit an increased propensity for solar PV adoption as part of their carbon-neutral practices when they perceive both the tangible and intangible environmental benefits of doing so, suggesting that emphasizing these benefits means that this technology represents a key lever for reducing environmental impact.

Additionally, as the direct influence of environmental concern on attitudes was comparatively weak, it suggests that attitudes are driven less by environmental concern as an intrinsic value or moral obligation than by perceived benefits. Consistent with findings that financial and technological burdens like high insertion cost and concerns at the end-of-life solar panel waste disposal typically dampened the effect of environmental concern on adoption behavior (Brown et al., 2021; Scheller et al., 2024). This finding adds to previous academic discussion which highlights the crucial importance of pragmatic considerations for environmentally motivated decisions. It concludes that beyond ideological or ethical motivations, the tangible and intangible, outcome-based evaluations by stakeholder guide individuals in their acts of sustainability. Although individuals have a moral obligation to engage in sustainable behavior, their actions are primarily driven by self-benefits.

The study also confirms that ATB is a crucial factor in determining the willingness to use solar PV technology. Individuals who exhibit a strong preference for carbon-neutral solutions tend to have a greater willingness to adopt solar PV. Moreover,

Table 12: PLS predict

Indicator	Q^2predict	PLS-SEM_RMSE	PLS-SEM_MAE	LM_RMSE	LM_MAE	IA_RMSE	IA_MAE
ATB1	0.455	0.645	0.514	0.646	0.523	0.873	0.729
ATB2	0.394	0.657	0.513	0.670	0.524	0.844	0.679
ATB3	0.433	0.714	0.547	0.729	0.553	0.948	0.788
ATB4	0.437	0.648	0.542	0.647	0.518	0.864	0.735
PENB1	0.569	0.605	0.472	0.614	0.477	0.921	0.750
PENB2	0.502	0.643	0.504	0.653	0.514	0.911	0.763
PENB3	0.544	0.576	0.455	0.591	0.466	0.854	0.713
PENB4	0.479	0.636	0.504	0.634	0.500	0.882	0.731
WTU1	0.462	0.682	0.559	0.684	0.557	0.931	0.745
WTU2	0.356	0.712	0.572	0.716	0.574	0.887	0.651
WTU3	0.374	0.730	0.580	0.744	0.585	0.923	0.668
WTU4	0.399	0.706	0.544	0.706	0.534	0.910	0.699

Source: PLS SEM Output (2025)

emotional engagement plays a significant role, as those who feel positively about installing solar PV technology are more inclined to proceed with adoption. The perception that transitioning to renewable energy sources is a rational and beneficial decision further strengthens individuals' motivation to invest in solar PV solutions. However, skepticism toward the feasibility of solar PV adoption can serve as a limiting factor, reinforcing the urgency of context-specific frameworks to neutralize misinformation and cognitive resistance.

This agrees with research indicating that ATB significantly influences willingness to adopt solar PV technology, particularly when individuals perceive strong economic, social, and environmental benefits (German et al., 2022; Lin et al., 2017; Mufidah et al., 2018). The results indicate that ATB significantly influences willingness to adopt, reinforcing the importance of cultivating positive perceptions of technology. According to the Theory of Planned Behavior (Ajzen, 1991; 2012; Bosnjak et al., 2020; Madden et al., 1992), attitude plays a fundamental role in shaping behavioral intentions, which is confirmed by studies highlighting that individuals with favorable attitudes toward solar PV are more likely to adopt it (Huang and Cheng, 2023; Zdonek et al., 2023). In commercial and industrial contexts, ATB reflects the perspective of business actors on technology as an innovative, efficient, and relevant solution to their energy needs. Consequently, building a favorable attitude toward solar technology is a critical first step in marketing strategies aimed at increasing adoption rates.

From an applied standpoint, these findings accentuate the need for targeted communication strategies that emphasize both the tangible and intangible environmental benefits of these carbon-neutral behaviors. This supports previous research emphasizing the role of evidence-based public awareness campaigns in increasing knowledge about solar PV technology and its environmental and economic advantages (Corbett et al., 2022; Zhao and Chen, 2021). Awareness campaigns should be designed to highlight clear, measurable advantages, such as reduced carbon emissions, improved air quality, and energy efficiency. Research on sustainable energy adoption indicates that emphasizing the long-term benefits of solar PV technology enhances public engagement and motivates behavioral change (Aghlimoghadam et al., 2022; Gelaidan et al., 2023).

Additionally, the study supports the implementation of evidence-based public awareness campaigns aimed at increasing knowledge about the benefits of implementing solar PV technology as a part of carbon-neutral actions. This aligns with findings that suggest educating individuals about the environmental, economic, and social benefits of sustainable practices can further strengthen positive attitudes and encourage broader adoption (German et al., 2022; Huang and Cheng, 2023; Lin et al., 2017). By focusing on both pragmatic and environmental concerns, policymakers and organizations can design more effective interventions to accelerate the transition toward renewable energy solutions. Informing individuals about the economic and social benefits of sustainable practices, alongside environmental considerations, may further strengthen positive attitudes and encourage broader adoption.

6. CONCLUSION

This study provides important theoretical and empirical contributions to the key role of perceived environmental benefit in forming and reinforcing pro-environmental attitude and behavior. The direct and indirect implications for both promoting sustainable actions and enhancing theoretical models of the broader scope of the protective effect of human experience, that harmonizes inherent psychological constructs with overlapping benefits of all actions, and specifically with sustainable actions, are two folds.

The present study makes significant theoretical contributions to our understanding of pro-environmental behavior by empirically establishing the partial mediating role of perceived environmental benefit. Such validation extends existing theoretical frameworks by describing the detailed cognitive processes that mediate concern for the environment with attitudes and behaviors. By mapping out the intricate along between psychology and sustainability, this study presents an enhanced analytic toolbox that enriches discussions concerning motivational predictors of renewable energy usage. Other studies indicate that environmental concern in itself is inadequate for stimulating a behavioral change, and this is a practical confirmation of that insight. These results underscore the importance of accounting for psychological constructs and perceived benefits in predicting pro-environmental behaviors.

In addition, the study confirms the role of psychology theories in predicting sustainable behavior patterns. The strong effects of perceived environmental benefits on attitudes confirm theoretical models that suggest that individuals make value judgements based on their perception of consequences and that such judgements exert strong influences on behavior. Future horizons of theories must include these implications in their fundamentals to expand their foresight ability and ethics.

Despite its contributions, this study is not without limitations. Although we encourage diversity in educational backgrounds that may reflect academic performance in real-life scenarios, we had limited insight into the geographical and cultural background of the participants, which may have affected the level of diversity in our sample. The generalizability of the findings may be in question due to differences in environmental attitudes and behaviours across regions and cultural backgrounds. These limitations are, on one hand, the reliance of quantitative methods, which, despite their robustness, are not sufficient to capture the intrinsic motives and context-dependent variables of behavior. In this regard, these findings could be complemented by a qualitative approach that explores in depth the psychological and social dimensions that underpin environmental decision-making.

Future investigations should also strive to validate these findings in different cultural and geographical settings to increase the external validity and generalizability of the findings. Cross context comparative studies could broaden understanding into how these variables function across the different contexts, offering not only insights into how environmental concern and perceived benefits function across these contexts, but also support better global sustainability efforts. Also, qualitative methods should be used in future research, to gain better insight into individuals' motivation and reasons for solar PV technology provision as the carbon-neutral energy source. To this end, such insights might contribute to the strategic toolkit of policymakers and private actors in their initiatives that succeed in closely linking macro sustainability targets with micro energy ambitions, potentially accelerating the broader integration and institutionalization of solar PV technology in the broader energy system context.

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