DIGITAL MARKETING AND CONSUMER KNOWLEDGE: RESIDENTIAL SOLAR ENERGY ADOPTION INTENTION THROUGH PERCEIVED SUSTAINABLE PRODUCT INNOVATION

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ABSTRACT

This study examines the influence of digital marketing and consumer knowledge on residential solar energy adoption intention, with perceived sustainable product innovation serving as a mediating variable. A quantitative survey approach was employed using data collected from 223 respondents in Indonesia and analyzed through Partial Least Squares Structural Equation Modeling (PLS-SEM). The findings demonstrate that digital marketing and consumer knowledge positively and significantly influence perceived sustainable product innovation and residential solar energy adoption intention. Perceived sustainable product innovation also significantly strengthens adoption intention and partially mediates the effects of both digital marketing and consumer knowledge. These findings indicate that consumers are more likely to consider adopting residential solar energy when they receive relevant and credible digital information, possess sufficient knowledge about solar technology, and perceive solar energy as an innovative and sustainable solution. The study contributes to the renewable energy adoption literature by integrating external marketing communication, internal consumer knowledge, and perceived sustainable innovation within a single consumer-level framework. It also highlights perceived sustainable product innovation as an important mechanism through which digital marketing and consumer knowledge translate into stronger adoption intentions. From a practical perspective, solar energy providers and related stakeholders should strengthen informative and credible digital communication, improve consumer understanding of solar technology, and emphasize its innovative and sustainability-related benefits. These efforts may help foster more favorable consumer perceptions and encourage greater intention to adopt residential solar energy.

Keywords : Digital Marketing; Consumer Knowledge; Perceived Sustainable Product Innovation; Residential Solar Energy; Adoption Intention

ABSTRAK

Penelitian ini mengkaji pengaruh digital marketing dan consumer knowledge terhadap niat adopsi energi surya rumah tangga, dengan perceived sustainable product innovation sebagai variabel mediasi. Pendekatan survei kuantitatif digunakan dengan melibatkan 223 responden di Indonesia, dan data dianalisis menggunakan Partial Least Squares Structural Equation Modeling (PLS-SEM). Hasil penelitian menunjukkan bahwa digital marketing dan consumer knowledge berpengaruh positif dan signifikan terhadap perceived sustainable product innovation serta niat adopsi energi surya rumah tangga. Perceived sustainable product innovation juga berpengaruh positif dan signifikan terhadap niat adopsi serta secara parsial memediasi pengaruh digital marketing dan consumer knowledge. Temuan ini menunjukkan bahwa konsumen cenderung memiliki niat adopsi yang lebih kuat ketika memperoleh informasi digital yang relevan dan kredibel, memiliki pengetahuan yang memadai mengenai teknologi surya, serta memandang energi surya sebagai solusi yang inovatif dan berkelanjutan. Penelitian ini memberikan kontribusi pada literatur adopsi energi terbarukan dengan mengintegrasikan digital marketing, consumer knowledge, dan perceived sustainable product innovation dalam satu kerangka pada tingkat konsumen. Penelitian ini juga menegaskan pentingnya perceived sustainable product innovation sebagai mekanisme yang menjembatani

pengaruh digital marketing dan consumer knowledge terhadap niat adopsi. Secara praktis, penyedia energi surya dan pemangku kepentingan terkait perlu memperkuat komunikasi digital yang informatif dan kredibel, meningkatkan pemahaman konsumen mengenai teknologi surya, serta menekankan manfaat inovasi dan keberlanjutannya untuk mendorong adopsi energi surya rumah tangga.

Kata Kunci : Digital Marketing; Consumer Knowledge; Perceived Sustainable Product Innovation; Energi Surya Rumah Tangga; Niat Adopsi

INTRODUCTION

The transition toward renewable energy has increased the importance of understanding how households evaluate and adopt cleaner energy technologies. Among available renewable energy alternatives, residential solar photovoltaic (PV) systems provide households with an opportunity to participate directly in the energy transition through decentralized electricity generation. However, residential solar adoption is not determined solely by technological availability. Consumer decisions are shaped by a combination of economic, technological, psychological, informational, and social considerations. Reviews of residential solar PV adoption research demonstrate that the literature remains dispersed across multiple behavioral determinants and theoretical perspectives, with the Diffusion of Innovations (DOI) framework and the Theory of Planned Behavior (TPB) among the commonly applied approaches (Alipour et al., 2021; Shakeel et al., 2023). This fragmentation indicates the need for more integrated explanations of how consumers obtain, interpret, and evaluate information before developing an intention to adopt residential solar energy.

Indonesia represents a relevant setting for examining this issue because existing studies indicate that residential rooftop solar adoption remains influenced by multiple barriers and facilitators. Bekti et al. (2021) found that price value contributes to attitudes and behavioral intention toward rooftop solar PV, while more recent Indonesian evidence identifies perceived cost, facilitating conditions, social influence, effort expectancy, and knowledge as factors associated with rooftop PV adoption intention (Eliva et al., 2025). From an economic perspective, Pramadya and Kim (2024) showed that the financial attractiveness of residential rooftop PV is highly dependent on incentive and policy conditions. Meanwhile, Afifi et al. (2025) found that household preferences remain relatively limited overall, although socioeconomic characteristics, environmental-community involvement, and exposure to peers using solar energy can strengthen willingness to adopt. Collectively, these studies demonstrate that residential solar adoption in Indonesia cannot be explained by technological or economic factors alone. Nevertheless, existing Indonesian studies have predominantly emphasized price, policy, technology-acceptance variables, socioeconomic factors, and social influence, leaving informational and innovation-perception mechanisms comparatively underexplored.

One potentially important informational mechanism is digital marketing. Digital platforms allow consumers to access information about solar technologies, environmental benefits, economic considerations, product characteristics, and installation alternatives through websites, social media, search engines, video platforms, and other online channels. Evidence from the broader green-consumption literature indicates that social media marketing can contribute positively to green purchase intention (Nekmahmud et al., 2022). Evidence from Indonesian consumer research further suggests that digital marketing can strengthen purchase intention, while social media marketing and sustainability-related knowledge are positively associated with intentions to purchase sustainable products (Az-Zahra & Sukmalengkawati, 2022; Diva & Pranatasari, 2023). In the solar-energy context, Kratschmann and Dütschke (2021) demonstrated that solar installers use digital websites to communicate economic and environmental arguments, although their study did not directly examine consumer responses. Bollinger et al. (2024) further showed through promotional campaigns that marketing activities and word of mouth can influence residential solar adoption, while Kumar (2025) highlighted the relevance of social-media information and collective intelligence in understanding solar-energy adoption. These studies suggest that digital communication can contribute to consumer decision-making. However, they do not establish how consumers' perceptions of the quality, credibility, interactivity, relevance, and usefulness of digital marketing information shape their evaluation of solar energy as a sustainable product innovation.

Alongside external information, consumer knowledge represents an important internal cognitive factor in technology adoption. Solar energy is a relatively high-involvement household technology that requires consumers to evaluate technological functions, environmental benefits, economic consequences, reliability, and long-term value. Consumers with greater product-specific knowledge may be better equipped to interpret such information and evaluate the benefits and limitations of solar technology. Cheam et al. (2021), in a residential solar PV context, found that knowledge positively influences adoption intention and that perceived usefulness mediates part of this relationship. Similarly, Asif et al. (2022) reported a positive relationship between environmental knowledge and solar-energy buying intention, while Saleem and Zhang (2024) found that knowledge contributes to household solar-energy consumption behavior. Evidence from renewable and green product contexts also indicates that consumer knowledge can positively influence attitudes, trust, purchase intentions, and sustainable consumption (Aslam et al., 2022; Hossain et al., 2022; Xin & Long, 2023; Tran & Vu, 2025). Evidence from Indonesian green-consumption research likewise indicates that environmental knowledge can positively influence green purchase behavior, reinforcing the role of consumer knowledge in sustainability-oriented decision-making (Haryanto et al., 2026).

Nevertheless, the effect of consumer knowledge is not entirely consistent across studies. Nautiyal and Lal (2022), for example, found that subjective knowledge did not significantly influence attitude or purchase intention, while objective knowledge played a different moderating role. Cha et al. (2024) similarly reported no clear relationship between general energy knowledge and household technology co-adoption. These mixed findings suggest that the influence of knowledge depends on how knowledge is conceptualized, the product context, and the mechanism through which consumers translate knowledge into evaluations and behavioral intentions. Therefore, rather than assuming that consumer knowledge automatically results in adoption intention, it is necessary to investigate the evaluative mechanism through which knowledge contributes to the formation of adoption decisions.

This study proposes perceived sustainable product innovation as such a mechanism. Sustainable product innovation has generally been examined from an organizational perspective, where green product innovation contributes to sustainable performance, competitive advantage, and broader organizational outcomes (Sarfraz et al., 2022; Awwad et al., 2022; Coelho et al., 2023). Digital information, customer integration, knowledge creation, and value co-creation have also been associated with innovation-related outcomes at the firm level (AlKoliby et al., 2023; Sun et al., 2023; Yin & Zhao, 2024). However, these studies conceptualize innovation primarily as an organizational capability or firm-level outcome. Such a perspective differs from how prospective consumers evaluate whether a product represents a meaningful sustainable innovation.

From a consumer perspective, perceptions of innovation may involve assessments of technological advancement, environmental benefits, efficiency, reliability, relative advantage, and economic value. Existing solar-adoption studies provide support for the relevance of these attributes without explicitly integrating them into a perceived sustainable product innovation construct. Grębosz-Krawczyk et al. (2021) demonstrated that functional and environmental values influence consumers' photovoltaic choices, while Kumar and Kaushik (2022) found that innovation-diffusion attributes such as relative advantage, compatibility, innovativeness, and observability contribute to rooftop solar adoption intention. Huang and Cheng (2022) also highlighted the relevance of consumer innovativeness and solar product knowledge in residential solar installation intention. These findings indicate that consumers' evaluations of innovative and sustainable product attributes may play an important role in adoption decisions. Yet the literature reviewed for this study does not explicitly examine perceived sustainable product innovation as a consumer-level mediating mechanism between digital marketing, consumer knowledge, and residential solar energy adoption intention.

Accordingly, a research gap emerges across the four literature streams. Residential solar adoption studies predominantly explain intention through economic, technological, social, environmental, and established technology-acceptance factors. Digital marketing research provides evidence concerning communication, social media, promotional campaigns, and innovation, but much of the innovation-related literature remains organizational rather than consumer-level. Consumer knowledge research demonstrates both positive and mixed effects on adoption-related outcomes, while sustainable product innovation studies largely focus on firm performance rather than consumer adoption. Within the literature reviewed for this study, these streams have not been integrated into an Indonesian consumer-level model in which digital marketing and consumer knowledge operate as parallel antecedents of perceived sustainable product innovation, which subsequently influences residential solar energy adoption intention while allowing direct effects from both antecedents. This integration provides the central research opportunity addressed by the present study.

Therefore, this study aims to examine the direct effects of digital marketing and consumer knowledge on residential solar energy adoption intention and to investigate the mediating role of perceived sustainable product innovation in these relationships. The study offers a theoretical contribution by integrating external digital information and internal consumer knowledge with consumers' evaluations of sustainable product innovation within a residential renewable-energy adoption framework. In particular, the study extends conventional solar-adoption research by examining not only whether digital information and consumer knowledge influence adoption intention, but also how these factors may operate through consumers' perceptions of sustainable innovation. From a practical perspective, the findings are expected to provide relevant insights for solar-energy providers, marketers, and other stakeholders in developing credible and informative digital communication, strengthening consumer understanding of residential solar technology, and emphasizing the technological, environmental, efficiency, reliability, and economic attributes that may strengthen consumers' willingness to adopt residential solar energy.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Theoretical Foundation

This study primarily draws on Diffusion of Innovations (DOI) and a consumer knowledge and information-processing perspective to explain residential solar energy adoption intention. DOI proposes that the adoption of an innovation depends substantially on how potential adopters perceive its characteristics, including relative advantage, compatibility, complexity, and observability. In the residential solar context, these innovation attributes are particularly relevant because solar photovoltaic technology represents a relatively complex,

high-involvement, and long-term household investment. Previous reviews confirm that DOI has been widely applied in explaining residential solar adoption, while empirical evidence shows that perceived relative advantage and other innovation characteristics can influence household adoption intention (Alipour et al., 2021; Shakeel et al., 2023; Kumar & Kaushik, 2022).

However, consumers cannot evaluate innovation attributes independently of the information available to them and their ability to interpret that information. Therefore, the present study complements DOI with a consumer knowledge and information-processing perspective. Digital marketing represents an external source of information through which consumers learn about solar technology, whereas consumer knowledge reflects the internal cognitive resources used to interpret technological, environmental, and economic information. Together, these factors may shape how consumers evaluate residential solar energy as an innovative and sustainable product. This theoretical integration provides the basis for examining perceived sustainable product innovation as a mechanism linking digital marketing and consumer knowledge with residential solar energy adoption intention.

Digital Marketing and Perceived Sustainable Product Innovation

Digital marketing enables firms to communicate product information through websites, social media, digital advertisements, search platforms, online videos, and other interactive channels. In the context of relatively complex products such as residential solar systems, the quality, credibility, relevance, interactivity, and responsiveness of digital communication may help consumers understand technological developments and evaluate the benefits offered by the product.

Previous research provides indirect support for a relationship between digital marketing and innovation. AlKoliby et al. (2023) demonstrated that digital marketing is associated with innovation in explaining sustainable performance, while Ravat et al. (2024) highlighted the role of marketing-related digital capabilities in developing innovation capability. Research on customer participation and digital environments also suggests that digital interaction and social media can facilitate green innovation processes (Sun et al., 2023; Yin & Zhao, 2024). Nevertheless, much of this evidence originates from the organizational level and conceptualizes innovation as a firm capability or outcome rather than as a consumer perception.

From the consumer perspective, digital marketing can reduce information asymmetry and make technological, environmental, and economic improvements more visible. When consumers encounter informative and credible digital content describing improvements in efficiency, reliability, environmental performance, and economic value, they may be more likely to perceive residential solar systems as meaningful sustainable innovations. Accordingly, the present study extends the organizational evidence to the consumer level.

H1: Digital marketing positively influences perceived sustainable product innovation.

Consumer Knowledge and Perceived Sustainable Product Innovation

Consumer knowledge refers to the extent to which consumers perceive themselves as understanding a product, its characteristics, benefits, operation, and consequences of use. For residential solar energy, relevant knowledge includes understanding solar technology, its environmental benefits, potential electricity-cost savings, operating characteristics, and advantages and limitations.

Knowledge plays an important role in the evaluation stage of innovation adoption because consumers with greater product knowledge are generally better able to interpret product-related information and distinguish relevant benefits from perceived risks or uncertainties. Cheam et al. (2021) found that knowledge contributes to residential solar PV adoption intention and that perceived usefulness can serve as an important mechanism in this relationship. Solar product knowledge has also been recognized as relevant to residential solar installation intention (Huang & Cheng, 2022). In broader sustainable-consumption contexts, environmental and product knowledge have been associated with perceived usefulness, trust, attitudes, and green consumption intentions (Hossain et al., 2022; Xin & Long, 2023; Tran & Vu, 2025).

However, knowledge effects are not universally consistent. Nautiyal and Lal (2022), for example, found that subjective knowledge did not always translate directly into favorable purchase outcomes, while Cha et al. (2024) reported an unclear relationship between general energy knowledge and household technology co-adoption. These mixed findings imply that knowledge may influence behavioral intention through consumers' evaluation of product attributes rather than through a purely direct process. Consumers who better understand solar technology should be more capable of recognizing its technological advancement, environmental contribution, energy efficiency, reliability, relative advantage, and economic value.

H2: Consumer knowledge positively influences perceived sustainable product innovation.

Perceived Sustainable Product Innovation and Residential Solar Energy Adoption Intention

Perceived sustainable product innovation in this study refers to consumers' evaluation of residential solar energy as an innovative product that offers technological advancement together with environmental, functional, and economic benefits. Unlike firm-level green innovation capability, the construct focuses on how prospective consumers perceive the innovative and sustainability-related attributes of the product.

The DOI perspective suggests that favorable perceptions of innovation characteristics should increase the probability of adoption. Empirical studies in the solar sector support this reasoning. Gręboszk-Krawczyk et al. (2021) found that functional and environmental values contribute to consumers' photovoltaic choices. Huang and Cheng (2022) identified perceived benefits and consumer innovativeness as relevant factors in residential solar installation intention. Similarly, Kumar and Kaushik (2022) demonstrated that attributes such as relative advantage, compatibility, observability, and innovativeness influence household rooftop solar adoption intention.

These findings suggest that consumers are more likely to adopt residential solar energy when they perceive the technology as providing meaningful improvements over conventional alternatives. A solar system that is perceived as technologically advanced, environmentally beneficial, energy-efficient, reliable, and economically valuable should therefore generate stronger adoption intention.

H3: Perceived sustainable product innovation positively influences residential solar energy adoption intention.

Digital Marketing and Residential Solar Energy Adoption Intention

Digital marketing may also influence adoption intention directly by providing consumers with information needed to evaluate residential solar energy. Digital communication can increase the accessibility of product information, clarify potential benefits, reduce uncertainty, and stimulate consumer interest in unfamiliar technologies.

Evidence from solar marketing research supports the relevance of communication in adoption decisions. Kratschmann and Dütschke (2021) showed that solar-energy marketing emphasizes economic and environmental arguments in communicating residential solar products. Bollinger et al. (2024) found that promotional campaigns and word of mouth can increase solar adoption, providing particularly strong evidence that marketing communication can influence actual consumer outcomes. Kumar (2025) further demonstrated the importance of social-media information in understanding solar-energy adoption, while Nekmahmud et al. (2022) found that social media contributes to consumers' green purchase intention.

Nevertheless, not all information exposure produces the same effect. Liu et al. (2023) found differences between forms of social learning, indicating that passive observation does not necessarily produce strong adoption effects. Therefore, the present study conceptualizes digital marketing not simply as exposure frequency, but as consumers' evaluation of informative, credible, attractive, interactive, responsive, and relevant digital communication. Effective digital marketing should consequently strengthen consumers' intentions to consider residential solar adoption.

H4: Digital marketing positively influences residential solar energy adoption intention.

Consumer Knowledge and Residential Solar Energy Adoption Intention

Consumer knowledge has received substantial attention in sustainable-consumption and renewable-energy research. Greater knowledge may reduce uncertainty, improve consumers' ability to evaluate costs and benefits, and increase confidence when considering complex household technologies.

Several studies provide direct or closely related evidence for this relationship. Eliva et al. (2025) identified knowledge as a relevant factor in rooftop PV adoption intention in Indonesia. Asif et al. (2022) found that environmental knowledge positively contributes to consumers' solar-energy buying intention, while Cheam et al. (2021) demonstrated a positive relationship between knowledge and residential solar PV adoption intention. Huang and Cheng (2022) also identified solar product knowledge as relevant to residential installation intention. Broader renewable-energy and green-consumption research similarly demonstrates positive associations between knowledge and sustainable purchase or consumption outcomes (Aslam et al., 2022; Xin & Long, 2023; Tran & Vu, 2025).

Although several studies report mixed or nonsignificant knowledge effects (Nautiyal & Lal, 2022; Cha et al., 2024), the overall evidence in the reviewed literature provides comparatively strong support for product-specific knowledge as an antecedent of solar adoption intention. Consumers who understand the operation, benefits, environmental effects, and economic implications of residential solar systems should be better positioned to form a confident intention toward future adoption.

H5: Consumer knowledge positively influences residential solar energy adoption intention.

The Mediating Role of Perceived Sustainable Product Innovation

The preceding arguments suggest that digital marketing and consumer knowledge may influence adoption intention not only directly but also indirectly by shaping consumers' perceptions of solar energy as a sustainable innovation. This mediating mechanism is theoretically important because receiving information or possessing knowledge does not automatically lead to behavioral intention. Consumers must first interpret that information and translate it into an evaluation of the product.

Digital marketing can communicate technological developments, environmental advantages, reliability improvements, efficiency gains, and economic benefits. Prior research demonstrates links between digital marketing and innovation-related outcomes (AlKoliby et al., 2023; Ravat et al., 2024) and between marketing communication and solar or green-consumption outcomes (Bollinger et al., 2024; Nekmahmud et al., 2022). At the same time, solar-adoption studies indicate that perceptions of relative advantage, functional value,

environmental value, and perceived benefits contribute to adoption intention (Gręposz-Krawczyk et al., 2021; Huang & Cheng, 2022; Kumar & Kaushik, 2022). Taken together, these streams imply that digital marketing may increase adoption intention partly because it improves consumers' perceptions of residential solar energy as an innovative and sustainable product.

However, the reviewed literature does not directly test the complete consumer-level pathway from digital marketing to perceived sustainable product innovation and subsequently to residential solar energy adoption intention. Therefore, this mediation represents an important extension of prior research.

H6: Perceived sustainable product innovation mediates the relationship between digital marketing and residential solar energy adoption intention.

A similar mechanism can be expected for consumer knowledge. Consumers with greater knowledge are better able to interpret information about technical performance, environmental benefits, reliability, and economic value. Knowledge has previously been associated with perceived usefulness, trust, attitudes, and adoption intentions (Cheam et al., 2021; Hossain et al., 2022; Xin & Long, 2023). Meanwhile, innovation-related product attributes and perceived benefits have been shown to influence residential solar adoption intention (Gręposz-Krawczyk et al., 2021; Huang & Cheng, 2022; Kumar & Kaushik, 2022).

Accordingly, consumer knowledge may strengthen adoption intention because knowledgeable consumers are more capable of recognizing the innovative and sustainability-related attributes of residential solar energy. This argument also provides a possible explanation for the mixed direct effects of consumer knowledge found in previous studies: knowledge may require a favorable product evaluation before translating into stronger behavioral intention. Because the exact mediation pathway remains underexplored in the reviewed literature, testing this relationship constitutes an additional contribution of the present study.

H7: Perceived sustainable product innovation mediates the relationship between consumer knowledge and residential solar energy adoption intention.

Proposed Research Model

Based on the theoretical arguments and previous empirical evidence, the proposed model examines digital marketing and consumer knowledge as parallel antecedents of both perceived sustainable product innovation and residential solar energy adoption intention. Perceived sustainable product innovation is positioned as a mediating construct while direct relationships between the two antecedents and adoption intention are retained. Consequently, the model simultaneously evaluates the direct and indirect mechanisms through which external digital information and internal consumer knowledge contribute to residential solar energy adoption intention.

RESEARCH METHOD

The study used a quantitative explanatory design based on cross-sectional survey data. Consumer perceptions, knowledge, and behavioral intentions were recorded within a single data-collection period (Creswell & Creswell, 2023). The cross-sectional design was used to test the hypothesized statistical relationships among the latent constructs; therefore, the estimated directional paths should be interpreted as theory-consistent associations and predictive relationships rather than evidence of temporal or causal effects. Given the reflective measurement specification and the inclusion of both direct and mediated relationships, the model was estimated using Partial Least Squares Structural Equation Modeling (PLS-SEM) (Hair et al., 2022).

Digital Marketing and Consumer Knowledge were modeled as exogenous constructs, Perceived Sustainable Product Innovation as the mediator, and Residential Solar Energy Adoption Intention as the endogenous construct. The specification therefore estimates the direct contribution of each antecedent to adoption intention together with its indirect contribution through Perceived Sustainable Product Innovation.

The study population comprised Indonesian adults who were already aware of residential solar technology. Purposive recruitment was conducted online from 29 August to 3 September 2026 by circulating the Google Forms link through Facebook groups, TikTok, and WhatsApp. Eligibility was assessed at the beginning of the questionnaire through screening questions covering willingness to participate, residence in Indonesia, age of at least 18 years, familiarity with solar photovoltaic (PV)/PLTS technology, and prior exposure to solar-panel information through digital media. A total of 223 main-survey submissions were received. Responses with incomplete screening or measurement data were predefined for exclusion; however, the exported dataset contained no missing responses, and all 223 submissions met the screening criteria. Because the questionnaire was anonymous, potential duplicate submissions were assessed using response timestamps and complete response-profile comparisons; no repeated timestamps or identical complete response profiles were identified. Accordingly, all 223 submissions were retained, yielding a 100% usable-case rate among submitted questionnaires. Because recruitment relied on an open social-media link, the number of individuals who viewed the invitation was unknown; therefore, a conventional invitation-to-response rate could not be calculated.

Sample adequacy was assessed using a sensitivity power analysis. Under a multiple-regression-equivalent framework with $N = 223$, a significance level of $\alpha = 0.05$, statistical power of 0.80, and a maximum of three predictors directed toward an endogenous construct, the minimum detectable effect size was approximately $f^2 = 0.050$. This result indicates that the final

sample provided sufficient statistical sensitivity to detect structural effects of approximately $f^2 = 0.05$ or greater (Hair et al., 2022).

Data collection was conducted with a self-administered questionnaire administered through Google Forms. The instrument contained screening items, demographic questions, and measurement statements for the four latent constructs. Gender, age, occupation, and interest in residential solar energy were used to describe the respondent profile. Each construct was operationalized by six reflective indicators, resulting in 24 indicators. Responses were recorded on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

The 24 measurement items were developed through literature-guided adaptation rather than adopted verbatim from a single established scale. The conceptual domain of each construct was mapped to relevant theoretical and empirical literature, and the resulting item wording was contextualized to residential solar energy in Indonesia. The questionnaire was developed and administered in Bahasa Indonesia; therefore, translation and back-translation procedures were not applicable. Prior to the main survey, the instrument was pilot-tested with 41 respondents who were independent of the final analytical sample. The pilot results informed minor wording revisions to improve clarity and contextual appropriateness. The final instrument retained six reflective indicators for each construct.

Digital Marketing (DM) captures how consumers judge the quality and effectiveness of digital communication about residential solar energy. Its six indicators are DM1 Information Clarity, DM2 Information Credibility, DM3 Content Attractiveness, DM4 Interactivity, DM5 Information Responsiveness, and DM6 Information Relevance. The item domains were developed from digital-marketing and digital-content literature emphasizing informative, relevant, engaging, and interactive communication (Kannan & Li, 2017; Hollebeek & Macky, 2019), and were contextualized using green- and solar-energy communication research (Kratschmann & Dütschke, 2021; Nekmahmud et al., 2022).

Consumer Knowledge (CK) measures subjective, product-specific understanding rather than knowledge verified through right-or-wrong testing. CK1 Basic Technology Knowledge, CK2 Functional Knowledge, CK3 Benefit Knowledge, CK4 Cost-Saving Knowledge, CK5 Environmental Knowledge, and CK6 Product Advantages and Limitations Knowledge capture consumers' perceived understanding of solar operation, household functions and benefits, economic implications, environmental consequences, and product trade-offs. The scale was developed from the consumer and product-knowledge literature distinguishing perceived knowledge and consumer expertise (Brucks, 1985; Alba & Hutchinson, 1987), with item wording contextualized using residential-solar product-knowledge studies (Cheam et al., 2021; Asif et al., 2022; Huang & Cheng, 2022).

Perceived Sustainable Product Innovation (PSPI) measures the extent to which consumers regard residential solar as both innovative and sustainable. The construct includes SPI1 Environmental Benefit, SPI2 Technological Advancement, SPI3 Energy Efficiency, SPI4 Safety and Reliability, SPI5 Relative Advantage, and SPI6 Long-Term Economic Value. Its item domains were developed by integrating green and sustainable product-innovation literature (Chen et al., 2006; Dangelico & Pujari, 2010), innovation attributes from Diffusion of Innovations (Rogers, 2003), and perceived-value logic (Zeithaml, 1988). The wording was then contextualized using solar-adoption evidence concerning environmental and functional value, relative advantage, and innovation-related product attributes (Grębosz-Krawczyk et al., 2021; Kumar & Kaushik, 2022).

Residential Solar Energy Adoption Intention (RSEAI) represents prospective willingness to consider household solar rather than actual installation. RSA1 Perceived Suitability, RSA2 Adoption Intention, RSA3 Willingness to Consider Adoption, RSA4 Future Adoption Plan, RSA5 Installation Consideration, and RSA6 Alternative Energy Choice capture suitability judgments, willingness, future plans, and consideration of solar as a household energy option. The item domains were guided by behavioral-intention and technology/innovation-adoption frameworks (Ajzen, 1991; Davis, 1989; Rogers, 2003) and were contextualized using empirical research on residential and rooftop solar adoption intention (Bekti et al., 2021; Asif et al., 2022; Huang & Cheng, 2022; Kumar & Kaushik, 2022).

Because all focal constructs were measured using the same self-administered questionnaire at a single point in time, the potential for common method bias was considered using both procedural and statistical approaches. Procedurally, participation was anonymous, and the questionnaire did not collect personally identifying information such as names or email addresses. Item wording was also refined following the pilot test to improve clarity and reduce measurement ambiguity. Statistically, full-collinearity variance inflation factors (VIFs) were assessed from the latent-variable scores by regressing each construct on the remaining constructs. Following Kock (2015), VIF values below 3.3 were interpreted as indicating that substantial common method bias was unlikely.

SmartPLS 4 was used for PLS-SEM estimation. For the reflective measurement model, the analysis considered outer loadings, Cronbach's alpha, rho_A, composite reliability, Average Variance Extracted (AVE), and the Heterotrait-Monotrait ratio (HTMT). Collinearity in the inner model was checked through Variance Inflation Factor (VIF) values. Structural assessment subsequently focused on path coefficients, R^2, f^2, direct effects, and specific indirect effects, following Hair et al. (2022) and Henseler et al. (2015).

Statistical inference used 5,000 bootstrap subsamples with two-tailed testing at the 5% level. Hypothesis decisions were derived from the estimated coefficients, t-statistics, p-values, and bootstrap confidence intervals. H1-H5 represent the direct relationships among the constructs, whereas H6 and H7 assess the indirect effects through Perceived Sustainable Product Innovation on Residential Solar Energy Adoption Intention. The mediation form was classified by examining the specific indirect effects together with their corresponding direct effects.

RESULTS AND DISCUSSION

Results

Respondent Characteristics

The final dataset comprised 223 respondents who satisfied the screening criteria. All participants provided consent, lived in Indonesia, were at least 18 years old, were familiar with solar photovoltaic (PV)/PLTS technology, and had encountered solar-panel information through digital media. Accordingly, all retained cases met the eligibility requirements.

Of the 223 respondents, 122 were male (54.7%) and 101 were female (45.3%). The 25-34-year group accounted for the largest share of the sample (35.0%, n = 78), followed by respondents aged 35-44 years (30.5%, n = 68), 18-24 years (23.3%, n = 52), 45-54 years (9.0%, n = 20), and 55 years or older (2.2%, n = 5). Employees constituted 48.4% of respondents (n = 108), entrepreneurs 32.3% (n = 72), students 15.2% (n = 34), and homemakers 4.0% (n = 9), as summarized in Table 1.

Respondents also demonstrated varying levels of interest in residential solar energy. Among the 223 respondents, 73 (32.7%) reported being very interested and 88 (39.5%) reported being interested in using solar panels for household purposes. Therefore, 72.2% of the respondents expressed either interest or strong interest in residential solar energy. Meanwhile, 38 respondents (17.0%) were moderately interested, 21 (9.4%) were less interested, and 3 (1.3%) were not interested. Although the respondents generally demonstrated a favorable orientation toward residential solar energy, the distribution also indicates sufficient variation in interest levels across the sample.

Descriptive Statistics

Construct-level statistics are presented in Table 2 using the average of the six indicators assigned to each variable. Mean scores for all constructs were above the scale midpoint. Consumer Knowledge recorded M = 3.839 (SD = 0.791), Perceived Sustainable Product Innovation M = 3.833 (SD = 0.784), Residential Solar Energy Adoption Intention M = 3.827 (SD = 0.812), and Digital Marketing M = 3.803 (SD = 0.809). The observed minimum and maximum for every construct were 1.000 and 5.000, respectively.

The descriptive results indicate that respondents generally perceived themselves as having relatively adequate knowledge of residential solar technology and evaluated solar panels favorably in terms of their sustainable innovation attributes. Respondents also demonstrated relatively positive intentions toward future residential solar adoption. Digital Marketing received a similarly favorable evaluation, suggesting that respondents generally perceived the digital information they encountered about residential solar technology as clear, credible, attractive, interactive, responsive, and relevant. Nevertheless, variation in the observed scores shows that the constructs were not evaluated uniformly, leaving sufficient dispersion for subsequent structural analysis.

Common Method Bias Assessment

The full-collinearity VIF values were 1.623 for Digital Marketing, 1.655 for Consumer Knowledge, 2.044 for Perceived Sustainable Product Innovation, and 2.358 for Residential Solar Energy Adoption Intention. All values were below the 3.3 threshold; accordingly, the full-collinearity diagnostic did not indicate substantial common method bias under this criterion (Kock, 2015).

Measurement Model Evaluation (Outer Model)

Measurement quality was established before interpreting the structural relationships. The reflective outer model was reviewed in terms of indicator reliability, internal consistency, convergent validity, and discriminant validity; the detailed results appear in Tables 3-5.

No indicator fell below the 0.70 loading criterion. As shown in Table 3, the 24 outer loadings varied from 0.711 to 0.851. The construct-specific ranges were 0.711-0.826 for Digital Marketing, 0.736-0.851 for Consumer Knowledge, 0.758-0.813 for Perceived Sustainable Product Innovation, and 0.766-0.812 for Residential Solar Energy Adoption Intention. DM3 produced the minimum loading (0.711), whereas CK2 produced the maximum (0.851); consequently, all indicators were retained.

Table 4 reports the internal-consistency results. Cronbach's alpha was 0.879 for Digital Marketing, 0.885 for Consumer Knowledge, 0.870 for Perceived Sustainable Product Innovation, and 0.880 for Residential Solar Energy Adoption Intention. The corresponding composite reliability (rho_c) coefficients were 0.909, 0.913, 0.902, and 0.909, while rho_A values lay between 0.872 and 0.888. As each coefficient exceeded 0.70, internal consistency was considered satisfactory (Hair et al., 2022).

Convergent validity was supported by AVE values of 0.624 for Digital Marketing, 0.637 for Consumer Knowledge, 0.606 for Perceived Sustainable Product Innovation, and 0.625 for Residential Solar Energy Adoption Intention. Thus, every construct exceeded the 0.50 AVE benchmark.

HTMT results in Table 5 were used to evaluate discriminant validity. The six construct-pair values extended from 0.532 to 0.775; the maximum ratio, 0.775, occurred between Perceived Sustainable Product Innovation and Residential Solar Energy Adoption Intention. All values remained under 0.85, providing support for discriminant validity.

Taken together, the measurement results satisfied the criteria required to proceed with structural-model evaluation.

Structural Model Evaluation (Inner Model)

Structural-model results are summarized in Table 6, and Figure 1 displays the estimated PLS-SEM model, including indicator loadings, structural coefficients, and R^2 values. The assessment addressed predictor collinearity, explanatory capacity, effect magnitude, and overall model fit.

The inner VIF statistics ranged between 1.282 and 1.622. Because these values were low, the structural estimates were not affected by problematic collinearity among the predictor constructs.

Digital Marketing and Consumer Knowledge explained 38.4% of the variance in Perceived Sustainable Product Innovation ($R^2 = 0.384$). For Residential Solar Energy Adoption Intention, the combined effects of Digital Marketing, Consumer Knowledge, and Perceived Sustainable Product Innovation explained 57.6% of the variance ($R^2 = 0.576$). The model therefore provided greater explanatory power for adoption intention than for the mediator.

The magnitude of individual effects varied by path. For Perceived Sustainable Product Innovation, f^2 equaled 0.202 for Consumer Knowledge and 0.131 for Digital Marketing. For Residential Solar Energy Adoption Intention, the f^2 values were 0.260 for Perceived Sustainable Product Innovation, 0.119 for Digital Marketing, and 0.074 for Consumer Knowledge.

Model fit was further assessed through SRMR. The obtained value of 0.057 was lower than the 0.08 reference value. Considered together with the R^2, f^2, and VIF evidence, this result indicated that the structural specification was adequate for evaluating the hypotheses.

Hypothesis Testing

The direct hypotheses were evaluated using the 5,000-subsample bootstrap procedure. Table 7 indicates that each of the five direct relationships reached statistical significance.

H1 was supported by the Digital Marketing -> Perceived Sustainable Product Innovation path ($\beta = 0.322$; $t = 4.035$; $p < 0.001$; 95% CI [0.161, 0.476]). H2 was likewise supported for Consumer Knowledge -> Perceived Sustainable Product Innovation ($\beta = 0.399$; $t = 5.811$; $p < 0.001$; 95% CI [0.264, 0.533]).

For H3, Perceived Sustainable Product Innovation showed the largest direct coefficient on Residential Solar Energy Adoption Intention (β = 0.423; t = 6.410; p < 0.001; 95% CI [0.290, 0.550]). The direct effects of Digital Marketing (β = 0.271; t = 3.607; p < 0.001; 95% CI [0.123, 0.420]) and Consumer Knowledge (β = 0.220; t = 3.302; p = 0.001; 95% CI [0.091, 0.355]) were also positive and significant, supporting H4 and H5.

Mediation Analysis

The mediation hypotheses were assessed from the specific indirect effects linking Digital Marketing and Consumer Knowledge to Residential Solar Energy Adoption Intention through Perceived Sustainable Product Innovation. Table 7 contains the corresponding bootstrap estimates.

For H6, the Digital Marketing -> Perceived Sustainable Product Innovation -> Residential Solar Energy Adoption Intention effect was significant (β = 0.136; t = 3.403; p < 0.001; 95% CI [0.062, 0.219]). Because the direct Digital Marketing -> Residential Solar Energy Adoption Intention effect was also positive and significant, Perceived Sustainable Product Innovation exhibited partial mediation.

H7 was supported by a significant Consumer Knowledge -> Perceived Sustainable Product Innovation -> Residential Solar Energy Adoption Intention effect (β = 0.169; t = 4.050; p < 0.001; 95% CI [0.095, 0.258]). The corresponding direct effect on adoption intention also remained significant, indicating partial mediation. Accordingly, empirical support was obtained for all seven hypotheses.

Discussion

H1 is supported, indicating a positive relationship between Digital Marketing and Perceived Sustainable Product Innovation. Consumers who encounter digital information that is clear, credible, attractive, interactive, responsive, and relevant tend to evaluate residential solar technology more favorably in terms of innovation and sustainability. In this sense, digital marketing contributes more than simple promotional exposure because it supplies informational cues for assessing technological, environmental, functional, and economic product attributes. This interpretation accords with evidence linking digital-marketing capabilities and digital customer participation to innovation-related outcomes (AlKoliby et al., 2023; Ravat et al., 2024; Sun et al., 2023; Yin & Zhao, 2024). Whereas much of that evidence concerns organizational innovation, the present result demonstrates a comparable association at the consumer level in the residential solar context.

H2 is also supported: Consumer Knowledge has a positive effect on Perceived Sustainable Product Innovation. Its coefficient (β = 0.399) exceeds that of Digital Marketing on PSPI (β = 0.322), indicating that consumers' own understanding of residential solar technology

is especially relevant to innovation evaluation. Knowledge of system operation, benefits, potential electricity-cost savings, environmental consequences, and product advantages and limitations helps consumers recognize the innovative value of the technology. This interpretation aligns with earlier evidence that consumer and environmental knowledge contribute to perceived usefulness, trust, attitudes, and evaluations of renewable and sustainable products (Cheam et al., 2021; Hossain et al., 2022; Xin & Long, 2023; Tran & Vu, 2025). The result also contributes to the mixed literature on subjective knowledge by showing a meaningful role for product-specific knowledge in evaluating sustainable innovation in residential solar energy.

H3 receives support from the positive effect of Perceived Sustainable Product Innovation on Residential Solar Energy Adoption Intention. With $\beta = 0.423$, PSPI is the strongest direct predictor in the model. Adoption intention is higher when solar panels are regarded as environmentally beneficial, technologically advanced, energy efficient, safe and reliable, advantageous relative to conventional alternatives, and economically valuable over the long term. This pattern accords with residential-solar evidence concerning functional and environmental value (Gręboszc-Krawczyk et al., 2021), perceived benefits and product knowledge (Huang & Cheng, 2022), and innovation attributes such as relative advantage (Kumar & Kaushik, 2022). Consistent with Diffusion of Innovations, favorable evaluation of innovation attributes can increase consumers' readiness to consider adoption. The result positions PSPI as a consumer-level mechanism through which perceptions of solar-technology attributes are associated with stronger adoption intention.

H4 is supported by the positive direct effect of Digital Marketing on Residential Solar Energy Adoption Intention. Favorable digital communication can strengthen willingness to consider residential solar energy by improving access to information on technology characteristics, household benefits, installation issues, prospective savings, and consumer experiences. Such information can reduce uncertainty surrounding a relatively complex household energy decision. The result is consistent with prior evidence that digital and social media marketing can shape consumer purchase intentions in general and sustainable-product contexts (Az-Zahra & Sukmalengkawati, 2022; Diva & Pranatasari, 2023; Nekmahmud et al., 2022), as well as with solar-specific evidence concerning marketing communication, promotional campaigns, social media, and word of mouth (Kratschmann & Dütschke, 2021; Bollinger et al., 2024; Kumar, 2025). At the same time, Liu et al. (2023) show that passive observation and meaningful social learning do not necessarily yield identical outcomes. The present evidence therefore emphasizes information quality and relevance rather than exposure alone.

The results further show that Consumer Knowledge positively affects Residential Solar Energy Adoption Intention, supporting H5. Consumers who perceive themselves as more knowledgeable about residential solar technology are more likely to consider its adoption in the future. Greater product-specific knowledge may reduce uncertainty and improve consumers' ability to assess the benefits, costs, environmental implications, and practical characteristics associated with residential solar energi. The result corresponds with previous studies linking product, environmental, and sustainability-related knowledge with adoption intention, perceived usefulness, trust, green purchase behavior, and other favorable consumer responses (Cheam et al., 2021; Asif et al., 2022; Saleem & Zhang, 2024; Eliva et al., 2025; Diva & Pranatasari, 2023; Haryanto et al., 2026).. Although its direct effect (β = 0.220) was smaller than that of PSPI, Consumer Knowledge remained statistically significant, confirming that knowledge has an independent role in explaining adoption intention.

The mediation results provide an additional contribution to the model. H6 is supported because Perceived Sustainable Product Innovation partially transmits the effect of Digital Marketing to Residential Solar Energy Adoption Intention. The indirect coefficient (β = 0.136) indicates that digital marketing is associated with adoption intention both directly and through more favorable evaluations of residential solar technology as innovative and sustainable. Effective digital communication can make technological advancement, environmental advantages, efficiency, reliability, relative advantage, and long-term economic value more salient to consumers, thereby strengthening adoption intention. Within the literature reviewed for this study, direct empirical evidence for the complete Digital Marketing -> Perceived Sustainable Product Innovation -> Residential Solar Energy Adoption Intention pathway remains limited. The result therefore links digital-marketing evidence with consumer-level perceptions of sustainable innovation.

H7 is likewise supported, with Perceived Sustainable Product Innovation partially carrying the effect of Consumer Knowledge to Residential Solar Energy Adoption Intention. The indirect effect (β = 0.169) suggests that product knowledge contributes to adoption intention partly by enabling consumers to identify and evaluate the innovative attributes of residential solar technology. Consumer knowledge therefore operates not only as a direct cognitive antecedent but also through the formation of favorable product evaluations. This result extends consumer-knowledge research by positioning PSPI as an explanatory mechanism connecting product-specific understanding with renewable-energy adoption intention.

Viewed jointly, the results describe a sequence in which external information, internal knowledge, and product evaluation contribute to residential solar adoption intention. Digital Marketing functions as the external informational component, Consumer Knowledge as the

internal cognitive component, and Perceived Sustainable Product Innovation as the evaluative component. Both antecedents retain direct relationships with adoption intention while also operating indirectly through PSPI. The R^2 of 0.576 indicates that, together, these three predictors account for 57.6% of the variance in Residential Solar Energy Adoption Intention.

The empirical pattern is consistent with the theoretical integration proposed in this study. Information-processing logic explains the role of digital-information quality and credibility in consumer evaluation, whereas the consumer-knowledge perspective accounts for the contribution of product understanding to informed judgment. Diffusion of Innovations clarifies the central role of PSPI because adoption depends partly on how consumers evaluate relative advantage, technological advancement, efficiency, reliability, environmental benefit, and economic value. PSPI therefore provides the evaluative link through which information and knowledge are connected with behavioral intention.

For residential solar-energy providers and related stakeholders, the results imply that digital strategies should prioritize informational quality rather than promotional reach alone. Online communication needs to be clear, credible, relevant, interactive, and responsive, while explaining both the benefits and limitations of residential solar technology. Particular attention should be given to technological advancement, energy efficiency, reliability, environmental benefits, relative advantage, and long-term economic value because these attributes underpin consumers' evaluations of sustainable innovation. Combining stronger digital communication with consumer education can therefore reinforce adoption intention directly and through more favorable perceptions of Perceived Sustainable Product Innovation.

CONCLUSION

The empirical evidence indicates that Digital Marketing and Consumer Knowledge contribute to Residential Solar Energy Adoption Intention both directly and through Perceived Sustainable Product Innovation among Indonesian consumers. Both antecedents are positively associated with PSPI and with adoption intention, while PSPI itself produces the strongest direct effect on adoption intention. The two significant indirect relationships show that PSPI partially carries the effects of Digital Marketing and Consumer Knowledge because the corresponding direct effects remain significant. These results position consumers' evaluation of residential solar technology as innovative and sustainable as a central explanatory mechanism connecting digital information and product knowledge with adoption intention.

The practical implication is that residential solar-energy providers and relevant stakeholders should integrate digital communication with consumer education. Digital content should communicate credible and relevant information about system operation, expected benefits, economic considerations, environmental implications, and practical limitations, while

remaining interactive and responsive to consumer information needs. Communication should also make salient the technological advancement, energy efficiency, reliability, environmental benefits, relative advantage, and long-term economic value of residential solar systems. Used in this manner, digital marketing serves not only a promotional function but also an educational function that can support more informed adoption decisions.

Several limitations define the scope of these findings. The cross-sectional design reflects perceptions and intentions observed at a single point in time and cannot establish temporal ordering or causal effects, including how intention develops into actual adoption over time. In addition, purposive non-probability sampling restricts the extent to which the results can be generalized to the Indonesian population, particularly because respondents already had some familiarity with solar technology and digital information. The dependent construct represents adoption intention rather than actual installation, which may also be conditioned by financial capacity, installation feasibility, regulation, incentives, and household circumstances. Consumer Knowledge was measured subjectively and therefore captures perceived product understanding rather than objectively tested knowledge. The model also excludes other potentially relevant determinants, including perceived cost, government incentives, perceived risk, social influence, environmental concern, and policy conditions.

Subsequent research could address these limitations by tracking respondents longitudinally to determine whether adoption intention is followed by actual residential solar-energy adoption. Broader geographical coverage and probability-based sampling would permit stronger population-level inference across Indonesia. Distinguishing subjective Consumer Knowledge from objectively assessed knowledge may also clarify whether the two forms of knowledge influence innovation perceptions and adoption decisions differently. Further models could incorporate perceived cost, financial incentives, government policy, perceived risk, trust, environmental concern, and social influence as antecedents, mediators, or moderators. Cross-regional or cross-country comparisons would additionally show whether the observed relationships are stable across different economic, technological, and regulatory settings.

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FIGURE AND TABLE

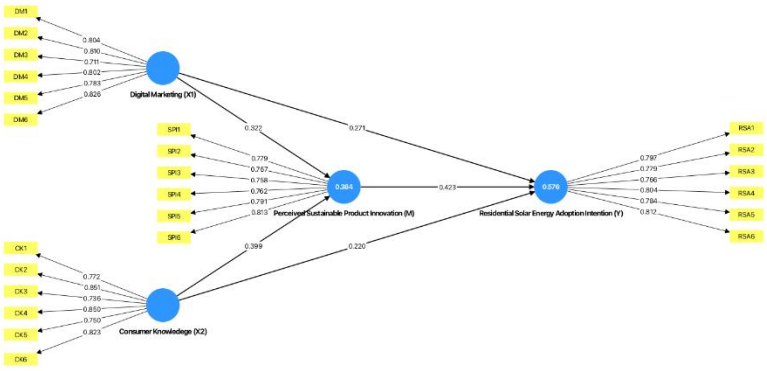


Figure 1. PLS-SEM Model Estimation Results
Source: Authors' analysis using SmartPLS 4 (2026)

Table 1. Respondent Characteristics

Characteristic	Category	Frequency (n)	Percentage (%)

Gender	Male	122	54.7
	Female	101	45.3
Age	18–24 years	52	23.3
	25–34 years	78	35.0
	35–44 years	68	30.5
	45–54 years	20	9.0
	≥55 years	5	2.2
Occupation	Student	34	15.2
	Employee	108	48.4
	Entrepreneur	72	32.3
	Homemaker	9	4.0
Interest in Residential Solar Energy	Very interested	73	32.7
	Interested	88	39.5
	Moderately interested	38	17.0
	Less interested	21	9.4
	Not interested	3	1.3

Table 2. Descriptive Statistics

Construct	Mean	SD	Minimum	Maximum
Digital Marketing	3.803	0.809	1.000	5.000
Consumer Knowledge	3.839	0.791	1.000	5.000
Perceived Sustainable Product Innovation	3.833	0.784	1.000	5.000
Residential Solar Energy Adoption Intention	3.827	0.812	1.000	5.000

Table 3. Outer Loadings of All Indicators

Indicator	Loading	Indicator	Loading	Indicator	Loading	Indicator	Loading
DM1	0.804	CK1	0.772	SPI1	0.779	RSA1	0.797
DM2	0.810	CK2	0.851	SPI2	0.767	RSA2	0.779
DM3	0.711	CK3	0.736	SPI3	0.758	RSA3	0.766
DM4	0.802	CK4	0.850	SPI4	0.762	RSA4	0.804
DM5	0.783	CK5	0.750	SPI5	0.791	RSA5	0.784
DM6	0.826	CK6	0.823	SPI6	0.813	RSA6	0.812

Table 4. Reliability and Convergent Validity

Construct	Cronbach's Alpha	rho_A	Composite Reliability (rho_c)	AVE
Digital Marketing	0.879	0.881	0.909	0.624
Consumer Knowledge	0.885	0.888	0.913	0.637
Perceived Sustainable Product Innovation	0.870	0.872	0.902	0.606
Residential Solar Energy Adoption Intention	0.880	0.881	0.909	0.625

Table 5. Discriminant Validity (HTMT)

Construct	DM	CK	SPI	RSA
Digital Marketing (DM)	—			
Consumer Knowledge (CK)	0.532	—		
Perceived Sustainable Product Innovation (PSPI)	0.577	0.621	—	
Residential Solar Energy Adoption Intention (RSEAI)	0.668	0.655	0.775	—

Table 6. Structural Model Assessment

Assessment	Construct / Relationship	Value	Interpretation
R^2	Perceived Sustainable Product Innovation (M)	0.384	38.4% variance explained
Adjusted R^2	Perceived Sustainable Product Innovation (M)	0.378	—
R^2	Residential Solar Energy Adoption Intention (Y)	0.576	57.6% variance explained
Adjusted R^2	Residential Solar Energy Adoption Intention (Y)	0.570	—
f^2	Digital Marketing (X1) → Perceived Sustainable Product Innovation (M)	0.131	Small effect
f^2	Consumer Knowledge (X2) → Perceived Sustainable Product Innovation (M)	0.202	Medium effect
f^2	Perceived Sustainable Product Innovation (M) → Residential Solar Energy Adoption Intention (Y)	0.260	Medium effect
f^2	Digital Marketing (X1) → Residential Solar Energy Adoption Intention (Y)	0.119	Small effect
f^2	Consumer Knowledge (X2) → Residential Solar Energy Adoption Intention (Y)	0.074	Small effect
Inner VIF	Digital Marketing (X1) → Perceived Sustainable Product Innovation (M)	1.282	No collinearity concern
Inner VIF	Consumer Knowledge (X2) → Perceived Sustainable Product Innovation (M)	1.282	No collinearity concern
Inner VIF	Perceived Sustainable Product Innovation (M) → Residential Solar Energy Adoption Intention (Y)	1.622	No collinearity concern
Inner VIF	Digital Marketing (X1) → Residential Solar Energy Adoption Intention (Y)	1.450	No collinearity concern
Inner VIF	Consumer Knowledge (X2) → Residential Solar Energy Adoption Intention (Y)	1.541	No collinearity concern
SRMR	Estimated model	0.057	Acceptable model fit (< 0.08)

Table 7. Hypothesis Testing and Mediation Results

Hypothesis	Relationship	β	t-statistic	p-value	95% CI	Decision
H1	DM (X1) → PSPI (M)	0.322	4.035	<0.001	[0.161, 0.476]	Supported
H2	CK (X2) → PSPI (M)	0.399	5.811	<0.001	[0.264, 0.533]	Supported
H3	PSPI (M) → RSEAI (Y)	0.423	6.410	<0.001	[0.290, 0.550]	Supported
H4	DM (X1) → RSEAI (Y)	0.271	3.607	<0.001	[0.123, 0.420]	Supported
H5	CK (X2) → RSEAI (Y)	0.220	3.302	0.001	[0.091, 0.355]	Supported
H6	DM (X1) → PSPI (M) → RSEAI (Y)	0.136	3.403	<0.001	[0.062, 0.219]	Supported (Partial mediation)
H7	CK (X2) → PSPI (M) → RSEAI (Y)	0.169	4.050	<0.001	[0.095, 0.258]	Supported (Partial mediation)

Note: DM = Digital Marketing; CK = Consumer Knowledge; PSPI = Perceived Sustainable Product Innovation; RSEAI = Residential Solar Energy Adoption Intention. H6 and H7 indicate partial mediation because the corresponding direct and indirect effects are both positive and significant.