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# Examining Social Acceptability of Solar Innovations in Smart Cities

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**Abstract**

*Objective:* The global challenge of climate change and the need for energy conservation have prompted a reevaluation of energy sources and policies worldwide. This study aims to investigate the societal acceptability of solar photovoltaic (PV) systems among citizens of smart cities, an aspect crucial yet underexplored in the context of renewable energy technologies. *Methods/Analysis:* A comprehensive survey was conducted involving 560 respondents to assess public perceptions, attitudes, and behaviors toward solar PV systems. The study also examined the moderating effects of area (urban/rural), gender, trust, and duration of use (experience) on societal acceptability. *Findings:* The results show that both independent and moderating variables significantly influence the social acceptability of solar innovations in smart cities. Key factors identified include the user-friendly design of solar systems, effective awareness campaigns highlighting their benefits, and compatibility with existing technologies. These elements are crucial in fostering positive attitudes and intentions towards the adoption of solar energy. *Novelty/Improvement:* This research provides valuable insights for policymakers, energy planners, and researchers, emphasizing the importance of considering demographic and experiential factors in policy-making. The findings suggest that societal acceptance of solar PV systems can be enhanced by targeting area-specific needs, leveraging trust, and promoting the benefits of prolonged usage experience.

*Keywords:* Technology Acceptance Model; Solar Systems; Energy Conservation; Renewable Energy; Societal Acceptability.

## 1. Introduction

Climate change and energy conservation are challenging countries and territorial organizations [1, 2]. The growth of a country and its incorporation into the global economy are significantly dependent on a stable energy source. It is a critical component of economic activity since it is an input into all industrial processes [3]. As economies grow, so does the global need for energy, yet demand for the various energy sources available is not uniformly distributed [4]. Therefore, many countries concentrate on environmental protection by encouraging sustainable growth. Countries are focusing on renewable energy sources, including solar and other green technologies, to harness valuable energy from sustainable sources and ensure a better global environment [5]. The transition to renewable energy sources, particularly solar power, is critical for achieving global sustainability goals and mitigating climate change. However, despite significant advancements in solar technology and its potential to reduce carbon emissions, the adoption of solar energy remains uneven. Understanding the factors influencing social acceptance of solar innovations is crucial for addressing barriers and enhancing adoption rates. This study aims to address gaps in the existing literature by exploring public willingness to adopt solar energy through different stages of willingness and patterns of social acceptance.

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Recent studies have highlighted the complexity of public acceptance of renewable energy technologies. For instance, Hai [6] explores the "states of willingness" to adopt solar energy in Finland, identifying four distinct states and five customer segments, predominantly reflecting an "acceptance in principle" pattern. This study underscores the need for nuanced approaches to address varying levels of willingness to adopt solar energy. Similarly, Billanes & Enevoldsen [7] apply the Technology Acceptance Model (TAM) to assess factors influencing residential adoption of Smart Energy Technologies (SETs) in Denmark, revealing that perceived ease of use, trust, and social influence significantly impact behavioral intention. However, perceived usefulness did not show a significant effect. It suggests that while ease of use and trust are crucial, perceived usefulness may not always be a dominant factor.

In contrast, Cousse [8] highlighted that the public's preference for solar energy diminishes when installations are scaled up, indicating that while solar power is favored, its large-scale deployment might face challenges. Haque et al. [9] emphasized the role of socio-cultural attitudes in the acceptance of solar technologies among low-income urban dwellers in Mumbai and Cape Town, suggesting that socio-cultural factors significantly influence technology adoption beyond mere economic benefits. Kapoor & Dwivedi [5] further support this by showing that factors like Compatibility and relative advantage have a substantial impact on consumer intentions to adopt solar innovations in India.

The case of Chandigarh's Solar Cities Programme, as analyzed by Garg & Barach [10], reveals that despite the high level of implementation and achievements, the lack of effective participatory planning and awareness efforts impeded long-term acceptance and sustainability. It points to the critical role of coordinated local planning and awareness in fostering adoption. Similarly, Rodríguez-Segura et al. [11] and Westerlund [12] showed that while there is a general acceptance of renewable energy in Spain, preferences vary based on installation size and location, highlighting the need for tailored policies to address local concerns. Finally, Lucchi et al. [13] addressed the integration of photovoltaic systems in heritage contexts, emphasizing that while economic and aesthetic benefits drive acceptance, cultural concerns pose significant barriers. This study points to the importance of considering cultural and aesthetic factors in promoting solar technology. While previous research has provided valuable insights into various aspects of solar energy adoption, there remains a need to explore how different stages of willingness and social acceptance patterns interact to influence overall adoption. This study builds on existing literature by examining these dynamics and offering a comprehensive analysis of factors influencing solar energy adoption in residential areas.

Pakistan relies heavily on hydroelectric power generation for its energy needs. Currently, hydropower stations are unable to meet the nation's energy needs. With the present energy crisis in mind, it is critical to reduce the shortfall by using renewable energy supplies [14]. Pakistan now produces 68% of its energy from thermal sources. Typically, thermal resources are expensive. By combining the use of thermal resources with government subsidies, the economy has been trapped in a cycle of debt, which slows down the execution of new projects [15]. It has placed a lot of stress on the economic cycle. By switching subsidized consumers (households) towards renewable energy sources, this burden can be decreased [4, 16]. According to one study, the complete power consumption of Pakistan can be fulfilled by installing solar PV with a 20% efficiency on 1% of Baluchistan land [17].

Many countries have established policies to promote renewable energy sources, including solar, wind, geothermal, biomass, and marine. Despite these policies being in place for over thirty years, societal acceptance of renewables has often been overlooked [18]. This oversight has contributed to the slow adoption of renewable energy worldwide, with limited awareness of societal acceptance challenges among policymakers and providers [19]. Social acceptability and political feasibility are crucial for successful low-carbon transitions [20]. In the 1990s, societal acceptance was primarily taken for granted due to general support for renewable technologies. However, the debate around social acceptance has evolved with new dimensions. Renewable energy projects are frequently smaller than traditional power plants, leading to more complex site considerations [21]. Additionally, renewable energy typically has lower energy densities, which increases its visible impact compared to fossil or nuclear energy, which is often less apparent to the public [2, 22]. Furthermore, due to prevalent externalities in the energy sector, renewable energy solutions frequently face unfair competition compared to established technologies, making acceptance a trade-off between immediate costs and long-term benefits [15].

In addition to these factors, the social acceptability of solar PV systems is also influenced by various socio-economic and market-related factors [23]. One of these factors is the public's attitude toward the solar PV system [3, 4]. The behavioral perspective in sustainable energy research is evolving rapidly [15]. While there is a substantial body of research on solar systems in Pakistan and people's attitudes toward them, there remains a research gap concerning the acceptability of solar systems, particularly among urban populations [18]. This research paper offers comprehensive insights into the public's acceptance of solar systems. The paper's organization is as follows. Section 2 discusses the related literature and conceptual framework. The research methodology is presented in section 3. The results of the study are elaborated in section 4. Section 5 provides a discussion of the results. Finally, the conclusion and future work direction are presented in section 6.

## 2. Literature Review and Formulation of Hypotheses

### 2.1. Conceptual Framework

The transition away from conventional energy sources and toward renewable energy sources is a socially driven process in which the attitudes of individuals play a critical part [19]. According to Do et al. [20], one of the primary impediments that can be attributed to the environmental policy implementation gap is the level of ecological literacy possessed by the general public. It is essential to keep in mind that the application of technology is significantly impacted by multi-faceted influences, which include societal, regulatory, and economic elements [21-23].

Several well-known models are used to understand and predict technology acceptance and usage. The Technology Acceptance Model (TAM), developed by Fred Davis in 1989, posits that perceived ease of use and perceived usefulness are critical predictors of technology adoption, suggesting that users are more likely to adopt technologies they find easy to use and beneficial. The Unified Theory of Acceptance and Use of Technology (UTAUT), introduced by Venkatesh et al. in 2003, integrates elements from TAM and other models, emphasizing performance expectancy, effort expectancy, social influence, and facilitating conditions while also considering factors like gender, age, and experience. The Theory of Planned Behavior (TPB), formulated by Icek Ajzen in 1991, extends the Theory of Reasoned Action (TRA) by adding perceived behavioral control, reflecting how control over one's behavior influences intentions and subsequent actions. Innovation Diffusion Theory (IDT), developed by Everett Rogers in 1962, explores how new ideas and technologies spread among individuals, focusing on factors like relative advantage, compatibility, complexity, trialability, and observability. The Motivational Model (MM) highlights the role of intrinsic and extrinsic motivations in technology adoption, suggesting that inherent satisfaction and external rewards drive usage. The Decomposed Theory of Planned Behavior (DTPB), proposed by Taylor and Todd in 1995, breaks down TPB's constructs into more specific components, offering a detailed analysis of the factors influencing technology acceptance. Lastly, Expectancy-Value Theory (EVT) combines expectancy and value elements to explain adoption behavior, proposing that individuals are motivated by their expectations of outcomes and the value they place on these outcomes. Each model offers unique insights into the psychological, social, and contextual factors affecting technology acceptance and usage [24].

Since the early 1990s, the study of user adoption of technology has been regarded as a highly significant academic topic [19]. Davis [25] devised the technology acceptance model, abbreviated as TAM, to identify the elements that contribute to the failure of systems and technology. In his model, Davis [25] argued that the motivations of users could be explained by the following three factors: the user’s attitude (ATTD) for technology usage, the user's perceived ease of use (EOUS), and the user's perceived usefulness (USFL) [25].

The focus of Davis [25] is on a particular kind of innovation. Davis’s TAM can be applied in many different contexts, but it is typically used to explain the variables that affect how technologies or information systems are used. Numerous research studies have extended the original TAM by looking at how different factors influence people's thoughts, feelings, and decisions to adopt a technology. TAM has also been used to develop a more in-depth framework of energy technology acceptance and explain why people plan to implement new sustainable energy technologies. Research has been done, for instance, to investigate homeowners’ attitudes toward having solar photovoltaic (PV) systems installed in their homes [26]. Socio-political, community, and market acceptance of renewable technology has also been investigated by Nkundabanyanga et al. [27]. In another study, Kardooni et al. [19] extended the TAM by including cost and knowledge as two external factors to examine their impacts on EOUS and USFL for onward shaping the attitudes toward using renewable energy.

According to the findings of these investigations mentioned above, the TAM is capable of functioning as an all-encompassing framework for the adoption or social acceptance of solar innovations. This conclusion was reached based on technological acceptance studies. Researchers can grasp the challenges that are faced by the development of solar innovations by utilizing TAM. Because of this, this framework was chosen for use in this study. Subsequently, the conceptual framework is depicted in Figure 1.

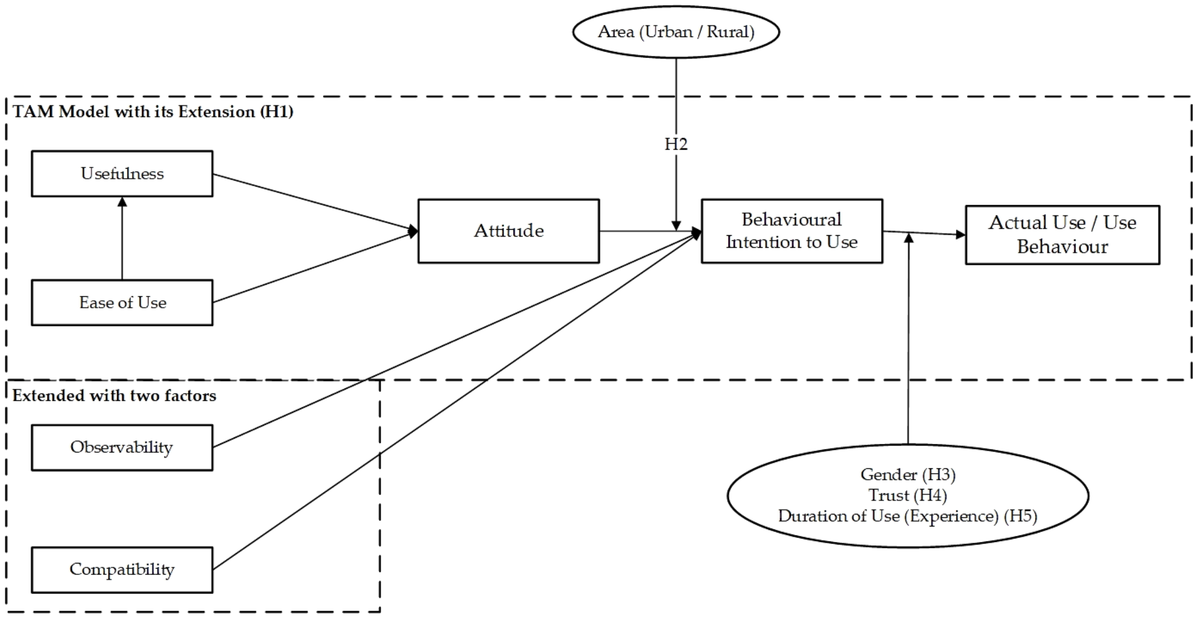


**Figure 1. Conceptual Framework for Social Acceptance of Solar Innovations**

### 2.2. TAM constructs, along with their Extension

***Usefulness*****:** Usefulness evaluates how successfully a solar innovation aids consumers in accomplishing their goals of reducing their electricity bills and assisting in the preservation of limited natural resources [28-31]. They preserve the environment by keeping it green and saving resources that are endangered. Suppose consumers meet their electrical demands using solar innovations instead of traditional sources like fossil fuel resources. In that case, they can complete more work in a shorter amount of time, and their output will be improved significantly [15, 26, 32]. Researchers argue that solar-based innovations are beneficial not only to homes but also to organizations. Studies on the social acceptability of solar-based innovations have been conducted to record the behavior of usefulness attributes and found that their impact is significant on attitude [26, 33, 34].

***Ease of Use*****:** According to Davis [25], EOUS is defined as the degree to which a person believes that using a particular system would be free of effort. It demonstrates how simple and hassle-free using solar energy is [15]. End users are more likely to use a solar innovation if it is easier to use [32, 35]. Consumers' perceptions of the amount of work required to use an innovation are frequently influenced by their familiarity with the innovation; the simpler an innovation is, the more appealing its potential adoption appears to be [29, 36]. According to the findings of a study on people's attitudes about the usage of solar innovation in their homes, solar power systems that are simple to operate have a greater chance of being purchased by potential customers [34, 37].

The influence of simplicity (ease of use) on solar innovation’s usefulness is a relationship that has received a lot of attention and investigation within the framework of innovation adoption [26, 31]. Cowan and Daim [38] provide a passing reference to this link in their research on energy-efficient technology; however, there is very little to no supporting empirical evidence of this commonly cited association in the body of research on solar and environmentally friendly developments.

***Observability***: Rogers [39] defines observability as the extent to which the results of an innovation are visible to target consumers, which can lead to its widespread adoption [17, 40]. Because of the nature of solar panels, they must be positioned on rooftops and typically have a high degree of visibility to others and observable results [41, 42]. Thus, the opportunity to observe rooftop solar panels in other people's homes may increase their adoption [43]. Moreover, Kapoor & Dwivedi [5] argued that sustainable advancements like household solar equipment are larger investments; hence, customers prefer rigorous evaluations before implementation. Studies on solar technology adoption have found positive effects of this feature on customer intentions. Studies like Kumar and Kaushik [16] on a household’s intention to purchase solar equipment, Elmustapha et al. [41] on household microgeneration technologies, and Kapoor & Dwivedi [5] on solar innovations also showed the significant positive impact of observability characteristics on such innovations.

***Compatibility***: According to Rogers [39], compatibility refers to how well an innovation aligns with users' past experiences, current values, and future needs [33, 44]. Consumers find innovations more appealing when they upgrade and satisfy their future wants or fit with their current lives [40, 43, 45]. The adoption of new micro-generation technologies, including domestic solar equipment, tends to make customers more hesitant when it comes to heating and electricity since they believe they will need to make big daily changes [41]. In their study on photovoltaic systems, Müller and Rode [46] found that these systems are compliant with existing rules and easy to use. Numerous studies on renewable energy innovations have documented the behaviour of this characteristic [5, 17, 47]. Each of these research studies found that compatibility had a considerable impact on consumer intention.

***Attitude*****:** Along with the Theory of Reasoned Action (TRA) [48] and the Theory of Planned Behavior (TPB) [49], TAM centers on attitudes [25]. These theories focus on how attitudes produce intentions that lead to observable behaviors. Attitudes are positive or negative appraisals of the results of a given behavior, such as adopting technology. Given their relevance in the preceding theories, attitudes have been widely investigated in the realm of up taking consumers’ intention to use solar-based innovations [26, 43, 50-53].

***Behavioral Intention*****:** Several theories of innovation diffusion and adoption argue that a person's behavioral intention is the most critical factor in determining whether an innovation will be adopted. This variable is hypothesized to be driven by instinct, which the customers typically associate with a particular pattern of behavior. Several studies have also highlighted it as a critical predictor of the adoption of solar innovations [26, 29, 35, 50-52]. However, quite a few studies have developed and investigated the relationship between BINT and AUSE [33, 54, 55].

***Hypothesis 1 (H1):*** The proposed model and its extension of the TAM would significantly predict social acceptance of solar innovation (this model is the base model without moderator variables).

### 2.3. Moderating Effects of Area (Urban / Rural), Gender, Trust, and Duration of Use (Experience)

A variable or construct is termed a moderator when it affects the strength (e.g., increase or decrease) of a relationship or even changes the direction of the relationship between two variables. Moreover, a moderator is a variable that has a solid contingent effect on the relationship between two variables [56]. It is argued that despite the variance explained by the proposed model being relatively high for behavioral research, researchers should attempt to identify and test additional boundary conditions of the model in an attempt to provide an even richer understanding of technology adoption and usage behavior [57]. Researchers suggest that the contingent effect of personality variables may be investigated for a richer understanding of the social acceptability of solar innovation [58]. Whereas previous research underscored the direct effects of gender and education [44] and trust [59] on the social acceptability of solar innovations, various studies indicate that exploring how gender influences consumer intentions could yield significant insights into the adoption of solar innovations [5]. According to Reyes-Mercado & Rajagopal [54], behavioral intentions and attitudes may differ based on consumers' area (e.g., Rural or Urban). Moreover, concerning consumers' gender, and area, studies showed mixed results in accepting solar innovations [60] and hence necessitated to confirm the results.

A scrutiny of the literature on solar innovations has found that area, gender, trust, and duration (experience) variables have not been introduced as moderator variables to make the social acceptability of solar innovations stronger or weaker. It should also be noted that the moderating effects of these variables have not been empirically tested on the solar innovations' social acceptability. Therefore, we assumed that these variables moderate different relationships in the social acceptability of solar innovations. Accordingly, the hypotheses are formulated as follows:

***Hypothesis 2 (H2):*** Area (Urban/Rural) has a moderating effect on the relationship between attitude and behavioral intention to use solar innovation.

***Hypothesis 3 (H3):*** Gender has a moderating effect on the relationship between behavioral intention and solar innovation usage.

***Hypothesis 4 (H4):*** Trust has a moderating effect on the relationship between behavioral intention and solar innovation usage.

***Hypothesis 5 (H5):*** Duration (experience) has a moderating effect on the relationship between behavioral intention and solar innovation usage.

## 3. Research Methodology

We adopted a deductive method, popularized by Austrian philosopher Karl Popper, to find the predictors of social acceptability of solar innovation among citizens of Smart Cities (including Karachi, Lahore, Islamabad, Bahawalpur, Peshawar, and Multan) of Pakistan (SCoP). Smart cities uniquely influence the social acceptability of solar innovations, extending beyond general attitudes towards renewable energy. In our study, we focused on smart cities because they often integrate advanced technology, infrastructure, and data-driven management systems that promote sustainable urban living. These characteristics create a conducive environment for adopting innovative technologies like solar PV systems.

Specifically, smart cities tend to have higher levels of awareness and education about renewable energy, as well as better access to information and resources, which can positively shape public perceptions and acceptance of solar innovations. Moreover, the presence of government initiatives, incentives, and supportive policies in smart cities can further enhance the attractiveness and feasibility of adopting solar energy solutions. The integration of solar innovations into the smart grid and other urban infrastructure also provides practical demonstrations of the technology's benefits, thereby reinforcing positive attitudes and social acceptability among residents. By focusing on smart cities, our study highlights the importance of urban environments that are inherently supportive of technological adoption, which in turn influences the broader societal acceptance of solar innovations.

Knowledge generation in the natural, social, and business sciences continues to rely heavily on this strategy despite several criticisms of the methodology and its application in social and business research [56]. Understanding how to generate knowledge to address fundamental and managerial issues is facilitated by the deductive method, a typical version of the scientific method. The deduced method goes from identifying a broad problem domain, defining the problem statement, formulating hypotheses, determining measures, and collecting and analyzing data to interpreting the data. We, specifically, followed the best practices proposed by Aguinis et al. [61] in collecting and preparing the data.

To compile this study's findings, the researchers collected data from the citizens of smart cities in Pakistan who had previously installed solar photovoltaic (PV) systems. The data was gathered from consumers (citizens of SCoP) during May 2022. Following the selection of appropriate demographics, constructs (variables), and items for the questionnaire based on previous research on solar innovations adoption, the questionnaire was subsequently constructed with the assistance of Google Forms. We used an online link to disseminate 1000 questionnaires in SCoP (see Appendix I). This method of data collection is simple and quick. Email and individual WhatsApp numbers were also used to spread the link to the online questionnaire to people who had solar-based energy systems installed in their homes. In SCoP, six hundred and thirty-five (635) responded to the survey by signing the online questionnaire link. The findings of a study (analyzing such a large sample size) can be extrapolated to a population of more than one million people, as suggested by the sample size criteria provided by Uma Sekaran and Roger Bougie [56]. Seventy-five (75) records were discarded during the analysis. A response rate of 56% was obtained, which was higher than the minimum acceptable response rate of 30% [56].

Given that there was no sampling frame available, this study employed a technique of non-probability sampling known as convenience sampling to find respondents so that they could provide their feedback on the predictors involved in predicting the social acceptability of solar innovations in citizens of SCoP. When the sampling frame is unavailable, convenience sampling can be an advantageous alternative [56]. In addition, the data for this study were collected with an online questionnaire from the citizens of SCoP. This method is recognized as a suitable way to obtain data associated with the topic of social acceptability of solar innovation in SCoP. A seven-point Likert scale, from strongly disagree (1) to strongly agree (7), was used to evaluate each item.

A minimum sample size was determined to carry out the primary analysis successfully. The sample size criteria given by Prajapati et al. [62] were implemented in the G*Power software (version 3.1.9.2) to achieve accuracy and reliability in statistical judgments. According to Prajapati et al. [62], four aspects should be considered when determining the minimum sample size. These criteria are the expected magnitude of the effect, the amount of probability involved, the level of statistical power involved, and the number of predictors. In this investigation, the minimal anticipated effect size was established at 0.15, the probability level was established at 0.001, and the statistical power level was established at 0.99 with seven (7) predictors. The smallest possible number of respondents was determined to be 315 for this research. The formal data-collecting method yielded 560 valid replies, which is more than the threshold sample size of 315.

The 560 survey respondents were selected using a stratified random sampling method to ensure a diverse and representative sample of the urban population in Pakistan. We stratified the sample based on key demographic variables such as geographic location (urban/rural), gender, and socio-economic status, which allowed us to capture a broad range of perspectives on solar PV systems. Respondents were chosen from various smart cities across different provinces, ensuring a mix of large metropolitan areas and smaller urban centers. We also applied data weighting techniques after the survey to adjust for any demographic imbalances, ensuring that the results accurately reflect the broader urban population. These steps were taken to enhance the reliability and generalizability of our findings.

Our study accounted for socio-economic, cultural, and geographic variations within Pakistan's urban population by including respondents from diverse income levels, educational backgrounds, and geographic locations. We stratified the sample to capture perspectives from both large metropolitan areas and smaller urban centers, and we included survey questions that explored cultural values and beliefs related to renewable energy. Additionally, geographic factors were analyzed using area (urban/rural) as a moderating variable. This approach allowed us to provide a nuanced understanding of how these variations influence the acceptability of solar PV systems in different urban contexts.

In quantitative studies, the development of a survey involving relevant constructs and their items is the fundamental part of data collection. An easy-to-fill, concise, and understandable survey motivates the respondents to fill it quickly. In this respect, a tool called Google Forms was used to design a survey questionnaire. However, items of the constructs that were included in the survey were taken from earlier literature on solar innovation. Four indicators of the perceived usefulness construct were taken from the study conducted by Nkundabanyanga et al. [27]. Furthermore, the constructs of ease of use, observability, compatibility, and behavioral intention, each featuring four indicators, were derived from the research conducted by Kapoor & Dwivedi [5]. Indicators of attitude were adopted from Ahmad et al. [26]. In contrast, statements of the actual use of solar innovation were adopted by considering the studies of Venkatesh & Bala [63] and Igbaria et al. [64].

Before responding to the questionnaire, citizens of SCoP are required to read the instruction section, which includes information on the goal of the research as well as how their responses will be kept confidential. The first part of the survey asked respondents to provide information that was linked to their demographic profiles. It included information such as their gender, age, qualification, area (urban or rural), duration, and willingness to buy solar panels on subsidized or not-subsidized rates, as shown in Figure 2.

The act of cleansing the data and bringing it into a state that is available for analysis is referred to as "data screening." The screening of the data consists of determining whether or not the data is valid, trustworthy, and testable [65]. The data were screened with consideration given to the three issues of missing data, checking outliers, and data normality [61]. Missing data refers to instances in which the respondent never answered a question or answered more than one question but did not fill out the questionnaire. Checking outliers is the statistical process in which the researchers check whether the respondent goes beyond the limits of pre-defined selections of responses, the same selections of options, or selections of options with a certain pattern. Normality of the data is also a statistical test to be conducted for testing the well-modelling of collected data. To test for normalcy, we ran descriptive statistics and set Skewness and Kurtosis ranges to +2 to -2 and +3 to -3, respectively. Skewness and Kurtosis were within range for all attributes [66, 67]. Following the resolution of these problems during the screening procedure for the data, 560 entirely usable questionnaires were selected for the subsequent analysis out of 635 that had been responded to by the citizens of ScoP.

To evaluate the proposed model, we employed Structural Equation Modeling (SEM), a robust statistical technique that allows us to assess the relationships between multiple independent and dependent variables simultaneously. SEM was particularly useful in determining the significance of both the direct effects of the independent variables and the moderating effects of the variables we considered. In our study, we used the Technology Acceptance Model (TAM) as the theoretical framework, integrating it with four essential moderators: area (urban/rural), gender, trust, and duration of use (experience). These moderators were included to examine how they influence the relationship between attitude, behavioral intention, and the usage of solar innovations. The results, as presented in Table 1, provide detailed insights into the significance and strength of these relationships. Each path coefficient was tested for statistical significance, allowing us to determine which moderating effects were significant and how they influenced the adoption and usage of solar innovations.

**Table 1. Hypothesis testing results**

| Hypothesis | Original Sample | Sample mean | Standard Deviation | T statistics | P values |
|---|---|---|---|---|---|
| ATTD → BINT | 0.829 | 0.829 | 0.023 | 36.246 | 0.000 |
| BINT → AUSE | 0.099 | 0.097 | 0.056 | 1.784 | 0.037 |
| COMP → AUSE | 0.050 | 0.054 | 0.057 | 0.883 | 0.189 |
| EOUS → ATTD | 0.331 | 0.328 | 0.051 | 6.479 | 0.000 |
| EOUS → USFL | 0.552 | 0.554 | 0.042 | 13.250 | 0.000 |
| OBSR → AUSE | 0.165 | 0.170 | 0.048 | 3.433 | 0.000 |
| USFL → ATTD | 0.450 | 0.452 | 0.051 | 8.907 | 0.000 |

Once the data was collected, the next step involved converting it into a suitable coding format. The data gathered via Google Forms was initially partially coded. To standardize this, one of the authors meticulously assigned codes to the initial values. For example, code 1 was used for urban areas and 2 for rural areas, while 1 represented males and 2 represented females. The analysis was carried out in SmartPLS 4.0.8.3, which is a well-known and widely used tool in the field of social science research. This was done after the data had been transformed and after checking for missing or comparable values in a given record. To develop the structural equation model, the SmartPLS 4 software employs a technique called Partial Least Squares Structural Equation Modeling (PLS-SEM). Given that this study aims to explore and extend an existing theory, parameter estimates were derived using repeated least squares regression with one dependent variable at a time. PLS-SEM was selected for its ability to handle data that does not adhere to normal distribution assumptions.

## 4. Analysis and Results

### 4.1. Demographic Profile of Respondents

Figure 2 offers valuable insights into the willingness and preferences of individuals in Pakistan regarding the adoption of solar-generated electricity. When examining the data in terms of geographical locations, it is evident that urban areas account for a significant majority, with 62.9% of respondents residing in urban regions compared to 37.1% in rural areas. This urban-rural divide may reflect differences in access to and awareness of solar energy solutions. Gender-wise data indicates that 67.5% of the respondents are male, while 32.5% are female. This gender disparity may reflect variations in decision-making power or access to information about solar energy technologies.

Most respondents showed a positive attitude toward the willingness to adopt solar energy. Specifically, 40.0% are willing to install solar systems and cover the costs if they receive a full 100% subsidy, while 28.8% would consider it with a 50% subsidy. A smaller percentage, 7.7%, is willing to pay without any subsidy, suggesting a willingness to invest in clean energy solutions. Furthermore, 67.7% of respondents are willing to use solar-generated electricity if the price is equivalent to fossil fuel-generated electricity. This indicates a positive attitude towards sustainability and a shift towards renewable energy sources.

The data also highlights the different applications of solar energy, with a significant 36.1% expressing interest in any other household solar system," indicating a diverse range of potential solar applications in Pakistan. When considering the duration of use, a substantial 36.3% are open to adopting solar energy within the first year, demonstrating a potential rapid uptake of this technology. Finally, while the age group "Less than 21 years" showed some interest, the bulk of respondents fall within the "21 to 30 years" bracket, suggesting that younger generations may be more open to adopting solar energy solutions. Regarding education levels, respondents with "A bachelor's degree" (34.8%) and "Masters degree" (41.4%) represent the largest segments, indicating that individuals with higher educational qualifications may be more inclined towards considering and adopting solar energy solutions. The data from Pakistan reflects a growing interest in solar-generated electricity, especially among urban and educated segments of the population. It also highlights the potential for the government and industry to promote solar adoption by offering subsidies and incentives to bridge the gap between willingness and actual implementation.

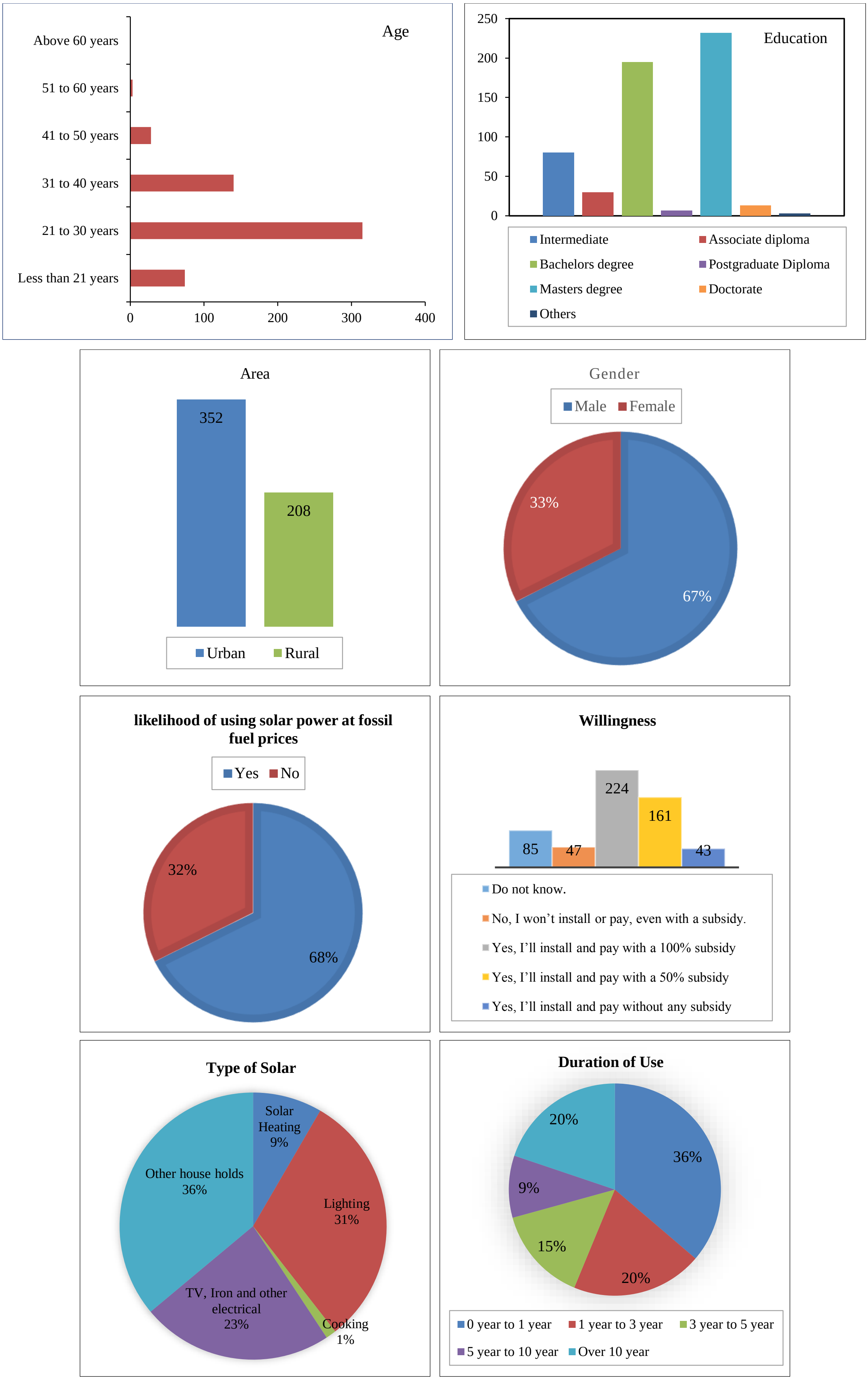


**Figure 2. Demographics profile of the respondents**

### 4.2. Test of Multicollinearity

Regression analysis would have issues if the predictors had a high degree of correlation. The Variance Inflation Factor (VIF) of each of the predictors must, therefore, be computed before performing regression and testing hypotheses. Multicollinearity is deemed not to exist if the value of each VIF for each predictor is found to be lower than 5 [65]. The degree of multicollinearity in the least squares regression analysis can be measured using the VIF. It provides feedback on how much collinearity has increased an estimated regression analysis's variance, which is the square root of standard deviation. The square of VIF shows how the standard error is higher than it would be if the variables in the relevant model were not linked with the other predictors. To put it more simply, if a predictor's VIF is x and its square root is y, we may say that the standard error of the predictor's coefficient is y times bigger than it would be if the predictors were not linked with one another. The value of each VIF of each predictor in the current investigation is far below 5, which is the acceptable number [65], indicating that there is no issue with multicollinearity among the predictor variables in this study.

### 4.3. Measurement Model

***Internal Consistency*****:** We calculated Cronbach's alpha and composite reliability values to determine the degree of reliability of the observed variables. According to Hair et al. [65], values of Cronbach's alpha are acceptable if they are greater than 0.7. At the same time, their lower limit may be adequate for an exploratory study at 0.6. Another researcher expressed the view that 0.60 is a reasonable lower limit for Cronbach's alpha [68]. Along with Cronbach's alpha, social scientists compute composite reliability, and its minimum acceptable value is also regarded as greater than 0.7. Table 2 displays both the estimates. Since we have already specified that the lowest acceptable value of Cronbach’s alpha is 0.6, Table 2 shows that the values of Cronbach's alpha range from 0.679 to 0.931, which confirms that the variables are reliable. Additionally, it appears from Table 2 that the results of the composite reliability test fall between 0.819 and 0.949, which is also appropriate because we are aware that the constant's lowest value should not be less than 0.7. We can, therefore, conclude that variables are reliable based on these estimates.

**Table 2. Internal Consistency and Convergent Validity**

| Constructs | Item Code | Factor Loadings | Cronbach’s Alpha | Composite Reliability | AVE |
|---|---|---|---|---|---|
| USFL | USFL01 | 0.797 | 0.891 | 0.920 | 0.697 |
| | USFL02 | 0.870 | | | |
| | USFL03 | 0.848 | | | |
| | USFL04 | 0.789 | | | |
| | USFL05 | 0.867 | | | |
| EOUS | EOUS01* | 0.028 | 0.679 | 0.819 | 0.604 |
| | EOUS02 | 0.839 | | | |
| | EOUS03 | 0.820 | | | |
| | EOUS04 | 0.659 | | | |
| COMP | COMP01 | 0.840 | 0.870 | 0.911 | 0.720 |
| | COMP02 | 0.857 | | | |
| | COMP03 | 0.823 | | | |
| | COMP04 | 0.872 | | | |
| OBSR | OBSR01 | 0.764 | 0.786 | 0.858 | 0.603 |
| | OBSR02 | 0.732 | | | |
| | OBSR03 | 0.779 | | | |
| | OBSR04 | 0.828 | | | |
| TRST | TRST01 | 0.807 | 0.789 | 0.848 | 0.589 |
| | TRST02 | 0.943 | | | |
| | TRST03* | 0.625 | | | |
| | TRST04 | 0.652 | | | |
| ATTD | ATTD01 | 0.893 | 0.928 | 0.949 | 0.822 |
| | ATTD02 | 0.920 | | | |
| | ATTD03 | 0.907 | | | |
| | ATTD04 | 0.906 | | | |
| BINT | BINT01 | 0.899 | 0.925 | 0.947 | 0.816 |
| | BINT02 | 0.888 | | | |
| | BINT03 | 0.918 | | | |
| | BINT04 | 0.909 | | | |
| AUSE | AUSE01 | 0.931 | 0.847 | 0.929 | 0.867 |
| | AUSE02 | 0.931 | | | |

Note: Actual Use (AUSE), Attitude (ATTD), Behavioural Intention (BINT), Compatibility (COMP), Ease of Use (EOUS), Observability (OBSR), Trust (TRST), Usefulness (USFL).

***Convergent Validity*:** To assess convergent validity, we evaluated the factor loadings of each item or indicator for the constructs in our model. Convergent validity is considered adequate if the factor loadings for each item are above 0.707, which indicates that each item reliably measures its intended construct. In our analysis, we included 31 indicators across seven variables. However, two items, EOUS01 (from the ease of use construct) and TRST03 (from the trust construct), were excluded from the final analysis. The item EOUS01 was discarded because its factor loading was below the acceptable threshold of 0.707, which means it did not adequately contribute to the construct.

Similarly, the item TRST03 was removed to improve the average variance extracted (AVE) of the trust construct. Consequently, we retained 29 items with satisfactory loadings, as shown in Table 2. We also assessed the average variance extracted (AVE) for each construct, which measures the extent to which items explain the variability of their respective constructs. The AVE should be at least 0.5 to ensure that the construct explains more than half of the variance in its items. As indicated in Table 2, all constructs in our study had AVE values greater than 0.5, confirming that the items effectively represent their constructs and support convergent validity.

***Discriminant Validity*:** For discriminant validity, items from one construct mustn't be overly correlated with items from other constructs, ensuring that each construct measures a distinct concept. We used the Heterotrait-Monotrait (HTMT) ratio, a robust criterion recommended by Hair et al. [65], to assess this. The HTMT ratio compares the correlations between items across different constructs and should be below a threshold value to confirm that constructs are sufficiently distinct from one another. According to Table 3, the HTMT ratios for all constructs are below the threshold value of 0.90, indicating that each construct measures a unique aspect of the study and that the constructs do not overlap excessively. It ensures that our model is valid in terms of both convergent and discriminant validity.

**Table 3. Discriminant Validity**

| | Actual Use | Attitude | Behavioral Intention | Compatibility | Ease of Use | Observability | Trust |
|---|---|---|---|---|---|---|---|
| **Attitude** | 0.144 | | | | | | |
| **Behavioral Intention** | 0.221 | 0.895 | | | | | |
| **Compatibility** | 0.217 | 0.732 | 0.726 | | | | |
| **Ease of Use** | 0.336 | 0.701 | 0.710 | 0.784 | | | |
| **Observability** | 0.263 | 0.446 | 0.456 | 0.538 | 0.720 | | |
| **Trust** | 0.126 | 0.752 | 0.723 | 0.801 | 0.777 | 0.607 | |
| **Usefulness** | 0.197 | 0.689 | 0.662 | 0.820 | 0.681 | 0.483 | 0.727 |

## 4.4. Structural Model

To evaluate the proposed model, we made use of something called Structural Equation Modeling (SEM). The SEM determines if the particular paths that are shown are reasonable or not. The path analysis provided in Table 1 offers valuable insights into the relationships between key variables within the research model. These relationships play a significant role in understanding the factors that influence the adoption and usage of a particular technology or behavior. The results are presented as p-values, which indicate the level of statistical significance for each path in the analysis.

Firstly, the path from attitude (ATTD) to behavioral intention (BINT) demonstrates a highly significant relationship, with a p-value of 0.000. It suggests that individuals' attitudes toward a technology or behavior are crucial in shaping their intentions to adopt it. A positive attitude likely leads to a stronger intention to use the technology or engage in the behavior, indicating that changing perceptions and fostering positive attitudes through awareness campaigns or educational efforts can be an effective strategy to increase adoption rates. Secondly, the path from behavioral intention (BINT) to actual usage (AUSE) is also significant, with a p-value of 0.037. This finding indicates that a strong intention to adopt a technology positively influences whether individuals will actually use it. This relationship underscores the importance of converting intention into action, suggesting that initiatives aimed at reinforcing intentions, such as follow-up support or reminders, can be critical in ensuring that expressed interest translates into real-world adoption.

In contrast, the path from Compatibility (COMP) to actual usage (AUSE) has a p-value of 0.189, which is higher than the conventional significance threshold of 0.05. While this relationship is not statistically significant, it may still hold practical importance. Compatibility refers to how well the technology fits with existing values, needs, and user experiences. Even though it may not be a strong direct predictor of usage, ensuring that new technologies align with users' lifestyles and preferences could still play a vital role in fostering long-term adoption and satisfaction. The paths from ease of use (EOUS) to both attitude (ATTD) and usefulness (USFL) exhibit highly significant relationships, with p-values of 0.000. It highlights that ease of use is a critical factor that influences both how favorably people view the technology (attitude) and how beneficial they perceive it to be (usefulness). User-friendly technologies are more likely to generate positive attitudes and be seen as valuable, suggesting that developers and policymakers should prioritize simplicity and usability in design and implementation to enhance acceptance and adoption.

The observed social influence (OBSR) also shows a highly significant relationship with actual usage (AUSE), with a p-value of 0.000. It indicates that when individuals observe positive outcomes and benefits from others using the technology, they are more likely to adopt it themselves. This finding underscores the power of social proof and the importance of visible success stories and testimonials in encouraging adoption. Lastly, the path from perceived usefulness (USFL) to attitude (ATTD) has a highly significant relationship, with a p-value of 0.000. It underscores the central role of perceived usefulness in shaping individuals' attitudes toward technology or behavior. When people believe that a technology will provide significant benefits, they are more likely to develop a positive attitude toward it, which in turn increases their intention to use it. Therefore, highlighting the tangible benefits and value of solar innovations is essential in driving positive attitudes and encouraging widespread adoption.

The findings of the structural model, along with moderating effects, are presented in Table 4. The $R^2$ value for the construct of usefulness (USFL) of solar innovations in Smart Cities of Pakistan (SCoP) is 0.305, meaning that the ease of use (EOUS) construct alone can explain 30.5% of the variance in how valuable people perceive solar innovations to be. It is a substantial percentage, indicating that ease of use is a critical factor in determining the perceived usefulness of solar technology in this context. Similarly, the construct of attitude (ATTD) towards using solar innovations in SCoP has an $R^2$ value of 0.476. It suggests that 47.6% of the variance in attitude can be explained by the combined influence of usefulness (USFL), ease of use (EOUS), observed social influence (OBSR), and compatibility (COMP). This relatively high $R^2$ value implies that these constructs are strong predictors of individuals' attitudes toward adopting solar innovations.

**Table 4. Testing of Hypotheses with Moderators**

| Paths | M1 | M2 | M3 | M4 |
|---|---|---|---|---|
| H1: USFL → ATTD | 0.450**** | M1 | M1 | M1 |
| EOUS → ATTD | 0.331**** | M1 | M1 | M1 |
| EOUS → USFL | 0.552**** | M1 | M1 | M1 |
| OBSR → BINT | 0.046** | 0.049** | 0.047** | 0.050** |
| COMP → BINT | 0.173**** | 0.168**** | 0.171**** | 0.167**** |
| ATTD → BINT | 0.829**** | 0.700**** | 0.741**** | 0.739**** |
| BINT → AUSE | 0.196**** | 0.212**** | 0.268**** | 0.275**** |
| H2: A*ATTD -> BINT | - | - | -0.098** | -0.085** |
| H3: G*BINT → AUSE | - | - | -0.227*** | -0.223*** |
| H4: D*ATTD -> BINT | - | -0.076*** | - | -0.072*** |
| H5: TRST*BINT -> AUSE | - | 0.057* | - | 0.051* |
| $R^2$ (Usefulness) | 0.305 | M1 | M1 | M1 |
| $R^2$ (Attitude) | 0.476 | M1 | M1 | M1 |
| $R^2$ (Behavioural Intention) | 0.710 | 0.716 | 0.713 | 0.719 |
| $R^2$ (Actual Use) | 0.038 | 0.044 | 0.052 | 0.057 |

When examining behavioral intention (BINT), the model shows an $R^2$ of 0.71, indicating that 71% of the variance in behavioral intention to use solar innovations can be explained by attitude (ATTD). It highlights a strong connection between an individual's attitude and their intention to adopt solar technologies. Interestingly, when the area (urban/rural) is introduced as a moderating variable, the $R^2$ value for behavioral intention slightly increases from 0.710 to 0.713. Although the increase is modest, it shows that geographic location adds a meaningful layer of influence, enhancing our understanding of how attitudes translate into behavioral intentions across different areas. Furthermore, for the actual use (AUSE) of solar innovations, the variance explained by behavioral intention (BINT) is initially 3.8% ($R^2$ = 0.038). However, when additional moderating variables—namely area, gender, duration of use, and trust—are considered, the explained variance increases to 5.7% ($R^2$ = 0.057). While this may seem like a slight increase, it is significant because it demonstrates that these moderators collectively play an important role in influencing the actual adoption of solar innovations.

It is also crucial to note that the effects of all these moderators—area, gender, duration, and trust—are statistically significant, underscoring their importance in understanding the social acceptability of solar innovations among citizens in SCoP. These findings suggest that policy and intervention strategies aiming to increase the adoption of solar technologies should consider these moderating factors to be more effective.

## 5. Discussion and Implications

This research examined the social acceptance of solar innovations among citizens of SCoP. The results of the hypothesis testing for a research study involving several variables and moderators provide valuable insights into the relationships between these factors. The research model comprises various factors, including usefulness, ease of use, compatibility, and observability, that influence the social acceptance (attitude, behavioral intention, and actual use) of solar innovations in citizens of SCoP. Additionally, there are four moderators, including area, gender, trust, and duration of use experience, to examine their moderating roles in influencing these relationships. Overall, the research model explains a substantial portion of the variance in USFL, ATTD, BINT, and AUSE by the innovation attributes and technology characteristics. This study also examines the results by comparing and contrasting prior research that has assessed citizens' behavior of embracing solar innovations in developed and emerging countries globally.

The results indicate that factors and interactions between variables have statistically significant effects, denoted by asterisks (*), on the relationships within the model. These considerable effects provide actionable insights for decision-makers and researchers in the context of solar innovation acceptability. Hypothesis H1 confirms that USFL and EOUS positively influence ATTD and that EOUS also positively affects USFL [32, 43]. These findings emphasize the importance of making solar innovations user-friendly and highlighting their usefulness in influencing users' attitudes positively. The results further show that OBSR and COMP have statistically significant impacts on BINT [16, 69].

On the contrary, according to the study of Alwedyan [70], COMP has no significant positive effect on BINT. The substantial impact on OBSR and COMP suggests that making the solar innovation's benefits observable to potential users and ensuring compatibility with their needs can enhance citizens’ intentions to use it. The proposed model also reveals a strong positive relationship between attitude (ATTD) and behavioral intention (BINT), indicating that a positive attitude toward solar innovations significantly influences the intention to accept it [32, 43, 69]. Interestingly, this study’s results confirm the positive impact of BINT on AUSE, implying that individuals who intend to accept solar innovations are more likely to put them into practice.

Hypotheses H2, H3, H4, and H5 highlight the moderating effects of different variables, such as area (A), gender (G), duration (D), and trust in the relationships within the model. These moderating effects signify that the context in which the acceptability of solar innovations occurs plays a crucial role in shaping the relationships between variables. Solar energy technology offers significant benefits for rural areas, particularly those that are not connected to the primary grid or experience extended periods of load shedding [18, 69]. Accordingly, the findings of this study reveal a strong positive impact on increasing the strength of the relationship between ATTD and BINT positively, which is, remarkably, aligned with the earlier study on the adoption of solar innovations [71]. Gender moderates the relationship between Behavioral Intention (BINT) and Actual Use (AUSE) of solar innovations, with a negative effect. This indicates that female family members in SCoP play a significant role in enhancing the social acceptability of solar technologies. It may be assumed by the results of this study that the female citizens in SCoP have greater influence in purchasing household items and decision-making powers at home. However, the results contradict the earlier study where females are less likely to accept solar innovations in their built environment [58].

Trust has also been recorded as the moderating variable in this study. It played a significant role in positively strengthening the relationship between BINT and AUSE. This means people with greater trust in solar technology transform their intentions into actual use of solar innovations. Moreover, as long as people are experiencing using solar technologies, their intentions toward using these technologies will be increased. In this way, the duration plays a moderating role in strengthening the relationship of BINT and AUSE. The more the citizens of SCoP would be experiencing using solar technology, the more they would perceive solar technology as a good idea. This ultimately increases their behavioral intention to use these technologies to a large extent. Overall, these results provide comprehensive insights into the factors that affect solar innovation acceptance in citizens of SCoP while considering the influence of moderators. In addition, this study’s results underscore the significance of user views, attitudes, and intentions in accepting solar innovations and highlight the importance of tailoring strategies to specific contexts, such as urban or rural areas, gender differences, and duration of technology use experience, and developing trust in solar innovations. Policymakers and practitioners can use these findings to design targeted interventions and initiatives to promote solar innovations’ acceptance more effectively in diverse settings.

The results of the demographic question (i.e., possibility) imply that around 68% of the smart cities’ citizens show their likelihood to use electricity generated by solar equipment, provided that the price is equal to the electricity generated from fossil fuels. The results contradict the findings of Abdullah et al. [72] because the Government of Pakistan (GoP) has provided substantial subsidies to the citizens to purchase solar panels in the country, which shapes their attitudes toward using solar PV technology. Moreover, a considerable ratio of citizens (around 69%) want to get at least 50% subsidies in installing and paying for solar PV systems, and thus, this significant ratio shows a substantial interest of people in installing and paying for solar systems at subsidized costs. A considerable interest increases the citizens’ intention to use solar innovations. Citizens or people of other developing countries bear the same perceptions when installing and buying such technology [18, 52, 73]. The impact of age is not revealed to be significant for the social acceptance of solar innovations in this study. Moreover, this variable also has no significant effect on the acceptance of solar innovations, as recorded in the survey conducted by Sposato & Hampl [58], mentioning that older participants are less likely to condone PV power plants in their neighborhoods.

The significant contributions of the independent and moderating variables in our study have direct implications for policy-making. For instance, the finding that urban areas exhibit higher acceptability of solar innovations suggests that urban policies should focus on financial incentives, while rural policies should aim to improve infrastructure and awareness. Gender differences in behavioral intention indicate the need for targeted campaigns that address gender-specific concerns. The role of trust underscores the importance of establishing certification programs and transparent information sources to build confidence in solar technology. Additionally, the influence of the duration of use suggests that policies should support long-term adoption through maintenance support or extended warranties. These insights can guide more effective, targeted policies that address specific needs and barriers within different segments of the population.

### 5.1. Theoretical Implications

This study empirically evaluates the social acceptability of solar innovations in citizens of ScoP by providing empirical insights into how TAM theory (USFL, PEOU) and its extended form (COMP, OBSR) behave in the context of SCoP's citizens. Further, the proposed model also provides empirical evidence of the extent to which the moderators (area (urban/rural), gender, trust, and duration of use) affect the associations between the independent and dependent variables for solar innovations' acceptance. The findings of this study provide a foundational basis for future research on solar innovations. They enhance the Technology Acceptance Model (TAM) by integrating elements from Rogers's Diffusion of Innovation Theory, offering a novel perspective on the adoption of solar technologies in Pakistan. The proposed model can be adapted and applied by future researchers to empirically test the effects of the hypothesized pathways on the acceptance of solar innovations or other sustainable technologies. With its global relevance, this framework, while developed within the context of Pakistan, is grounded in broader knowledge about the worldwide diffusion of solar innovations.

Consequently, it holds significant potential for informing similar environmentally beneficial advancements in various countries and communities. This study investigates the influence of four key attributes on attitude, intention, and actual usage, with a particular emphasis on serial mediation. It builds on insights from two established theories in information systems: the Technology Acceptance Model and the Diffusion of Innovation Theory. Although there is limited evidence in the existing literature on the complete model (mostly limited to only behavioural intentions) and moderating effects of certain variables in the context of solar innovations, four relationships were proposed based on logical reasoning: (a) EOUS has an impact on USFL, (b) EOUS and USFL have impacts on ATTD, (c) OBSR and COMP have impacts on BINT, (d) ATTD affects BINT, and (e) BINT has an impact on AUSE. These relationships were found to be significant, resulting in comprehensive interpretative results overall. Thus, the results of this research expand knowledge by revealing novel behaviours of the variables involved, thereby enriching the current understanding within a theoretical framework by providing more insights.

### 5.2. Practical Implications

The Government of Pakistan (GOP) has introduced various initiatives to foster the adoption of solar innovations, including subsidies, tax reductions, and installment plans. These measures are designed to benefit households, farmers, and industries, reflecting the GOP's strong interest in advancing solar technology. Additional policies are under development to support this transition further. The initial findings of this study offer valuable insights into consumer demographics, which can aid in profiling and segmenting consumers based on their interests [5]. From a managerial perspective, understanding these demographic factors is crucial for developing targeted strategies that address the needs of different customer segments. Given that compatibility and observability significantly impact consumer intention, marketing strategies should focus on demonstrating the benefits of solar innovations and their alignment with daily consumer demands. Specifically, marketing should emphasize that adopting residential solar technology will not necessitate significant lifestyle changes while still enhancing living standards.

## 6. Conclusion

The pressing global concerns of climate change and the necessity for energy conservation have led nations to reassess their energy policies and sources. A stable and sustainable energy supply is vital for both economic growth and environmental protection. In Pakistan, where hydroelectric power generation falls short of energy demands, transitioning to renewable sources like solar power is imperative to relieve the economic strain of thermal resources. However, the societal acceptability of renewable energy technologies, especially solar systems, remains a critical yet underexplored issue. Understanding public attitudes and behaviors towards solar systems in urban settings is crucial for informed policy decisions and sustainable energy transitions. This study seeks to investigate the societal acceptability of solar photovoltaic (PV) systems among urban populations in Pakistan. It aims to evaluate attitudes, behavioral intentions, and actual usage while identifying influential factors. Through a comprehensive survey and path analysis techniques, this research addresses the gap in understanding the acceptability of solar PV systems in urban Pakistan, contributing to sustainable energy research and promoting the adoption of solar PV systems to address energy deficits and environmental challenges in the region.

The results of this research study offer profound insights into the multifaceted dynamics of factors influencing the adoption of a particular technology or behavior. The numerous hypotheses and their corresponding significance levels illustrate that the data support the research model well. Perceived usefulness, ease of use, compatibility, and attitude emerge as pivotal factors, exhibiting strong and significant relationships with behavioral intention and actual use. Importantly, the study acknowledges the contextual complexities through the introduction of moderators, such as area, gender, duration, and education. These moderators highlight that the impact of these factors can vary significantly across different contexts, emphasizing the need for tailored interventions and policies.

The high R-squared values for attitude and behavioral intention underscore the model's predictive power in explaining these constructs, offering practical value for those seeking to influence and understand these outcomes. The findings also have direct implications for decision-makers, policymakers, and marketers. Policymakers can leverage the insights to design policies and incentives aligned with influential factors like perceived usefulness and trust. Marketers can design persuasive campaigns by focusing on compatibility and ease of use as critical drivers of behavioral intention. Furthermore, these results advocate for cross-functional collaboration among researchers, policymakers, and practitioners to develop effective strategies that consider both the direct and moderating effects of various factors.

While these findings provide valuable insights, they also invite further exploration. Future research endeavors may delve into experimental studies or longitudinal analyses to investigate causal relationships and delve deeper into the intricacies of technology or behavior adoption. In essence, this study lays the foundation for evidence-based strategies, acknowledging the nuanced interplay of factors and the importance of context in driving successful adoption initiatives.

## 7. Declarations

### 7.1. Author Contributions

Conceptualization, M.M.K. and H.M.F.S.; methodology, M.M.K.; software, U.A.; validation, M.M.K., A.R., and U.A.; formal analysis, A.R.; investigation, U.A.; resources, A.R.; data curation, M.M.K.; writing—original draft preparation, M.M.K.; writing—review and editing, H.M.F.S.; visualization, U.A.; supervision, A.R.; project administration, U.A.; funding acquisition, A.R. and U.A. All authors have read and agreed to the published version of the manuscript.

### 7.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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### 7.4. Conflicts of Interest

The authors declare no conflict of interest.

## 8. References

[1] Nazir, L., & Sharifi, A. (2024). An analysis of barriers to the implementation of smart grid technology in Pakistan. Renewable Energy, 220. doi:10.1016/j.renene.2023.119661.

[2] Maqsoom, A., Hammad, M., Umer, M., Salman, A., & Ashraf, H. (2024). From intentions to actions: unveiling the socio-psychological drivers of solar home system adoption in developing nations. Architectural Engineering and Design Management. doi:10.1080/17452007.2024.2316658.

[3] Ferreira, L., Oliveira, T., & Neves, C. (2023). Consumer’s intention to use and recommend smart home technologies: The role of environmental awareness. Energy, 263. doi:10.1016/j.energy.2022.125814.

[4] Schulte, E., Scheller, F., Sloot, D., & Bruckner, T. (2022). A meta-analysis of residential PV adoption: the important role of perceived benefits, intentions and antecedents in solar energy acceptance. Energy Research and Social Science, 84. doi:10.1016/j.erss.2021.102339.

[5] Kapoor, K. K., & Dwivedi, Y. K. (2020). Sustainable consumption from the consumer’s perspective: Antecedents of solar innovation adoption. Resources, Conservation and Recycling, 152. doi:10.1016/j.resconrec.2019.104501.

[6] Hai, M. A. (2019). Rethinking the social acceptance of solar energy: Exploring "states of willingness" in Finland. Energy Research & Social Science, 51, 96–106. doi:10.1016/j.erss.2018.12.013.

[7] Billanes, J., & Enevoldsen, P. (2022). Influential factors to residential building Occupants' acceptance and adoption of smart energy technologies in Denmark. Energy and Buildings, 276, 112524. doi:10.1016/j.enbuild.2022.112524.

[8] Cousse, J. (2021). Still in love with solar energy? Installation size, affect, and the social acceptance of renewable energy technologies. Renewable and Sustainable Energy Reviews, 145, 111107. doi:10.1016/j.rser.2021.111107.

[9] Haque, A. N., Lemanski, C., & de Groot, J. (2021). Why do low-income urban dwellers reject energy technologies? Exploring the socio-cultural acceptance of solar adoption in Mumbai and Cape Town. Energy Research & Social Science, 74, 101954. doi:10.1016/j.erss.2021.101954.

[10] Garg, B., & Barach, R. (2021). Collaborative governance for urban sustainability: implementing solar cities. Asia Pacific Journal of Public Administration, 43(4), 236–257. doi:10.1080/23276665.2021.1925132.

[11] Rodríguez-Segura, F. J., Osorio-Aravena, J. C., Frolova, M., Terrados-Cepeda, J., & Muñoz-Cerón, E. (2023). Social acceptance of renewable energy development in southern Spain: Exploring tendencies, locations, criteria and situations. Energy Policy, 173, 113356. doi:10.1016/j.enpol.2022.113356.

[12] Westerlund, M. (2020). Social acceptance of wind energy in urban landscapes. Technology Innovation Management Review, 10(9), 49–62. doi:10.22215/TIMREVIEW/1389.

[13] Lucchi, E., Adami, J., & Stawinoga, A. E. (2023). Social acceptance of photovoltaic systems in heritage buildings and landscapes: Exploring barriers, benefits, drivers, and challenges for technical stakeholders in northern Italy. Sustainable Energy Technologies and Assessments, 60, 103544. doi:10.1016/j.seta.2023.103544.

[14] Mehmood, F., Umar, M., Dominguez, C., & Kazmi, H. (2022). The role of residential distributed energy resources in Pakistan's energy transition. Energy Policy, 167. doi:10.1016/j.enpol.2022.113054.

[15] Iten, R., Wagner, J., & Zeier Röschmann, A. (2024). On the Adoption of Smart Home Technology in Switzerland: Results from a Survey Study Focusing on Prevention and Active Healthy Aging Aspects. Smart Cities, 7(1), 370–413. doi:10.3390/smartcities7010015.

[16] Kumar, V., & Kaushik, A. K. (2022). Solar rooftop adoption among Indian households: a structural equation modeling analysis. Journal of Social Marketing, 12(4), 513–533. doi:10.1108/JSOCM-07-2021-0170.

[17] Qureshi, T. M., Ullah, K., & Arentsen, M. J. (2017). Factors responsible for solar PV adoption at household level: A case of Lahore, Pakistan. Renewable and Sustainable Energy Reviews, 78, 754–763. doi:10.1016/j.rser.2017.04.020.

[18] Jan, I., Ullah, W., & Ashfaq, M. (2020). Social acceptability of solar photovoltaic system in Pakistan: Key determinants and policy implications. Journal of Cleaner Production, 274. doi:10.1016/j.jclepro.2020.123140.

[19] Kardooni, R., Yusoff, S. B., & Kari, F. B. (2016). Renewable energy technology acceptance in Peninsular Malaysia. Energy Policy, 88, 1–10. doi:10.1016/j.enpol.2015.10.005.

[20] Do, T. N., Burke, P. J., Baldwin, K. G. H., & Nguyen, C. T. (2020). Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam. Energy Policy, 144. doi:10.1016/j.enpol.2020.111561.

[21] Kiefer, C. P., & del Río, P. (2020). Analysing the barriers and drivers to concentrating solar power in the European Union. Policy implications. Journal of Cleaner Production, 251. doi:10.1016/j.jclepro.2019.119400.

[22] Alipour, M., Irannezhad, E., Stewart, R. A., & Sahin, O. (2022). Exploring residential solar PV and battery energy storage adoption motivations and barriers in a mature PV market. Renewable Energy, 190, 684–698. doi:10.1016/j.renene.2022.03.040.

[23] Asante, D., He, Z., Adjei, N. O., & Asante, B. (2020). Exploring the barriers to renewable energy adoption utilising MULTIMOORA- EDAS method. Energy Policy, 142. doi:10.1016/j.enpol.2020.111479.

[24] Alshammari, S. H., & Rosli, M. S. (2020). A review of technology acceptance models and theories. Innovative Teaching and Learning Journal, 4(2), 12-22.

[25] Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. MIS Quarterly, 13(3), 319. doi:10.2307/249008.

[26] Ahmad, S., Mat Tahar, R. bin, Cheng, J. K., & Yao, L. (2017). Public acceptance of residential solar photovoltaic technology in Malaysia. PSU Research Review, 1(3), 242–254. doi:10.1108/PRR-11-2016-0009.

[27] Nkundabanyanga, S. K., Muhwezi, M., Musimenta, D., Nuwasiima, S., & Najjemba, G. M. (2020). Exploring the link between vulnerability of energy systems and social acceptance of renewable energy in two selected districts of Uganda. International Journal of Energy Sector Management, 14(6), 1089–1122. doi:10.1108/IJESM-08-2019-0007.

[28] Sommerfeld, J., Buys, L., & Vine, D. (2017). Residential consumers' experiences in the adoption and use of solar PV. Energy Policy, 105, 10–16. doi:10.1016/j.enpol.2017.02.021.

[29] Sahu, G. P., Singh, P., & Dwivedi, P. (2021). Adoption of solar energy in India: a study through interpretive structural modelling. World Journal of Science, Technology and Sustainable Development, 18(4), 457–473. doi:10.1108/WJSTSD-04-2021-0043.

[30] Sawyer, S. W. (1982). Leaders in change. Solar energy owners and the implications for future adoption rates. Technological Forecasting and Social Change, 21(3), 201–211. doi:10.1016/0040-1625(82)90050-6.

[31] Lau, L. S., Senadjki, A., Ching, S. L., Choong, C. K., Seow, A. N., Choong, Y. O., & Wei, C. Y. (2021). Solar photovoltaic as a means to sustainable energy consumption in Malaysia: the role of knowledge and price value. Energy Sources, Part B: Economics, Planning and Policy, 16(4), 303–323. doi:10.1080/15567249.2021.1922545.

[32] Bouaguel, W., & Alsulimani, T. (2022). Understanding the Factors Influencing Consumers' Intention toward Shifting to Solar Energy Technology for Residential Use in Saudi Arabia Using the Technology Acceptance Model. Sustainability (Switzerland), 14(18), 18. doi:10.3390/su141811356.

[33] Ahmed, Y. A., Rashid, A., & Khurshid, M. M. (2022). Investigating the Determinants of the Adoption of Solar Photovoltaic Systems—Citizen's Perspectives of Two Developing Countries. Sustainability (Switzerland), 14(18), 18. doi:10.3390/su141811764.

[34] Aravindan, K. L., Thurasamy, R., Raman, M., Ilhavenil, N., Annamalah, S., & Rathidevi, A. S. (2022). Modeling Awareness as the Crux in Solar Energy Adoption Intention through Unified Theory of Acceptance and Use of Technology. Mathematics, 10(12), 12. doi:10.3390/math10122045.

[35] Alam, S. S., Nik Hashim, N. H., Rashid, M., Omar, N. A., Ahsan, N., & Ismail, M. D. (2014). Small-scale households renewable energy usage intention: Theoretical development and empirical settings. Renewable Energy, 68, 255–263. doi:10.1016/j.renene.2014.02.010.

[36] Khalid, B., Urbański, M., Kowalska-Sudyka, M., Wysłocka, E., & Piontek, B. (2021). Evaluating consumers' adoption of renewable energy. Energies, 14(21), 21. doi:10.3390/en14217138.

[37] Alam, S. S., Ahmad, M., Othman, A. S., Shaari, Z. B. H., & Masukujjaman, M. (2021). Factors affecting photovoltaic solar technology usage intention among households in Malaysia: Model integration and empirical validation. Sustainability (Switzerland), 13(4), 1–20. doi:10.3390/su13041773.

[38] Cowan, K. R., & Daim, T. U. (2011, July). Understanding adoption of energy efficiency technologies: applying behavioral theories of technology acceptance & use to understand the case of LED lighting for commercial, residential, and industrial end-users. 2011 Proceedings of PICMET'11: Technology Management in the Energy Smart World (PICMET), 31 July 2011 - 04 August 2011, Portland, United States.

[39] Rogers, E. M. (2003). Diffusion of Innovations. (5th Ed.). Free Press, New York, United States.

[40] Rachmawati, I., Loy, N., & Karolus, M. L. (2023). Solar electricity: A dimming ray of hope in Ngada, East Nusa Tenggara, Indonesia. Social Sciences & Humanities Open, 8(1), 1. doi:10.1016/j.ssaho.2023.100574.

[41] Elmustapha, H., Hoppe, T., & Bressers, H. (2018). Consumer renewable energy technology adoption decision-making; comparing models on perceived attributes and attitudinal constructs in the case of solar water heaters in Lebanon. Journal of Cleaner Production, 172, 347–357. doi:10.1016/j.jclepro.2017.10.131.

[42] Wolske, K. S., Stern, P. C., & Dietz, T. (2017). Explaining interest in adopting residential solar photovoltaic systems in the United States: Toward an integration of behavioral theories. Energy Research & Social Science, 25, 134–151. doi:10.1016/j.erss.2016.12.023.

[43] Kumar, P., Kumar, P., & Aggarwal, V. (2024). A behavioral study on villagers' adoption intention and carbon neutrality toward rooftop solar photovoltaic systems in India. International Journal of Energy Sector Management, 18(1), 200–227. doi:10.1108/IJESM-11-2021-0009.

[44] Shakeel, S. R., Yousaf, H., Irfan, M., & Rajala, A. (2023). Solar PV adoption at household level: Insights based on a systematic literature review. Energy Strategy Reviews, 50. doi:10.1016/j.esr.2023.101178.

[45] Kumar, P., Gupta, S., & Dagar, V. (2024). Sustainable energy development through non-residential rooftop solar photovoltaic adoption: Empirical evidence from India. Sustainable Development, 32(1), 795–814. doi:10.1002/sd.2644.

[46] Müller, S., & Rode, J. (2013). The adoption of photovoltaic systems in Wiesbaden, Germany. Economics of Innovation and New Technology, 22(5), 519–535. doi:10.1080/10438599.2013.804333.

[47] Labay, D. G., & Kinnear, T. C. (1981). Exploring the Consumer Decision Process in the Adoption of Solar Energy Systems. Journal of Consumer Research, 8(3), 271. doi:10.1086/208865.

[48] Fishbein, M., & Ajzen, I. (1977). Belief, attitude, intention, and behavior: An introduction to theory and research. Addison-Wesley, Boston, United States.

[49] Ajzen, I. (1991). The theory of planned behavior. Organizational Behavior and Human Decision Processes, 50(2), 179–211. doi:10.1016/0749-5978(91)90020-T.

[50] Rezaei, R., & Ghofranfarid, M. (2018). Rural households' renewable energy usage intention in Iran: Extending the unified theory of acceptance and use of technology. Renewable Energy, 122, 382–391. doi:10.1016/j.renene.2018.02.011.

[51] Sun, P. C., Wang, H. M., Huang, H. L., & Ho, C. W. (2020). Consumer attitude and purchase intention toward rooftop photovoltaic installation: The roles of personal trait, psychological benefit, and government incentives. Energy and Environment, 31(1), 21–39. doi:10.1177/0958305X17754278.

[52] Shakeel, S. R., & Rahman, S. U. (2018). Towards the establishment of renewable energy technologies' market: An assessment of public acceptance and use in Pakistan. Journal of Renewable and Sustainable Energy, 10(4), 4. doi:10.1063/1.5033454.

[53] Rai, V., & Beck, A. L. (2015). Public perceptions and information gaps in solar energy in Texas. Environmental Research Letters, 10(7), 7. doi:10.1088/1748-9326/10/7/074011.

[54] Reyes-Mercado, P., & Rajagopal, R. (2017). Adoption of renewable energy technologies in Mexico: The role of cognitive factors and innovation attributes. International Journal of Energy Sector Management, 11(4), 626–649. doi:10.1108/IJESM-02-2017-0001.

[55] Alipour, M., Stewart, R. A., & Sahin, O. (2021). Beyond the diffusion of residential solar photovoltaic systems at scale: Allegorising the battery energy storage adoption behaviour. Energies, 14(16), 5015. doi:10.3390/en14165015.

[56] Sekaran, U. (2016). Research methods for business: A skill building approach. John Wiley & Sons, Hoboken, United States.

[57] Venkatesh, Morris, Davis, & Davis. (2003). User Acceptance of Information Technology: Toward a Unified View. MIS Quarterly, 27(3), 425. doi:10.2307/30036540.

[58] Sposato, R. G., & Hampl, N. (2018). Worldviews as predictors of wind and solar energy support in Austria: Bridging social acceptance and risk perception research. Energy Research & Social Science, 42, 237–246. doi:10.1016/j.erss.2018.03.012.

[59] Chidembo, R., Francis, J., & Kativhu, S. (2024). Underlying beliefs that influence solar home system adoption in Vhembe district Municipality, South Africa. Social Sciences & Humanities Open, 9. doi:10.1016/j.ssaho.2023.100754.

[60] Kizilcec, V., Perros, T., Bisaga, I., & Parikh, P. (2022). Comparing adoption determinants of solar home systems, LPG and electric cooking for holistic energy services in Sub-Saharan Africa. Environmental Research Communications, 4(7), 7. doi:10.1088/2515-7620/ac7f23.

[61] Aguinis, H., Hill, N. S., & Bailey, J. R. (2019). Best Practices in Data Collection and Preparation: Recommendations for Reviewers, Editors, and Authors. Organizational Research Methods, 24(4), 678–693. doi:10.1177/1094428119836485.

[62] Prajapati, B., Dunne, M., & Armstrong, R. (2010). Sample size estimation and statistical power analyses. Optometry today, 16(7), 10-18.

[63] Venkatesh, V., & Bala, H. (2008). Technology acceptance model 3 and a research agenda on interventions. Decision Sciences, 39(2), 273–315. doi:10.1111/j.1540-5915.2008.00192.x.

[64] Igbaria, M., Iivari, J., & Maragahh, H. (1995). Why do individuals use computer technology? A Finnish case study. Information & Management, 29(5), 227–238. doi:10.1016/0378-7206(95)00031-0.

[65] Hair, J.F., Hult, G.T.M., Ringle, C.M. and Sarstedt, M. (2017) A Primer on Partial Least Squares Structural Equation Modeling (PLS-SEM) (2nd Ed.). Sage Publications Inc., Thousand Oaks, United States.

[66] Garson, G. D. (2012). Testing statistical assumptions. NC Statistical Associates Publishing, Asheboro, United States.

[67] Curran, P. J., West, S. G., & Finch, J. F. (1996). The Robustness of Test Statistics to Nonnormality and Specification Error in Confirmatory Factor Analysis. Psychological Methods, 1(1), 16–29. doi:10.1037/1082-989X.1.1.16.

[68] Nunnally, J. C., & Bernstein, I. H. (1994). Psychometric theory (3rd Ed.). McGraw-Hill, New York, United States.

[69] Liu, D., Qi, S., & Xu, T. (2023). Visual observation or oral communication? The effect of social learning on solar photovoltaic adoption intention in rural China. Energy Research & Social Science, 97. doi:10.1016/j.erss.2023.102950.

[70] Alwedyan, S. (2021). Factors Influencing the Adoption Intentions of Households toward Solar Photovoltaic Technology in Jordan: A Structural Equation Modeling Analysis. The Arab World Geographer, 24(4), 285-302. doi:10.5555/1480-6800.24.4.285.

[71] Aarakit, S. M., Ntayi, J. M., Wasswa, F., Adaramola, M. S., & Ssennono, V. F. (2021). Adoption of solar photovoltaic systems in households: Evidence from Uganda. Journal of Cleaner Production, 329. doi:10.1016/j.jclepro.2021.129619.

[72] Abdullah, Zhou, D., Shah, T., Jebran, K., Ali, S., Ali, A., & Ali, A. (2017). Acceptance and willingness to pay for solar home system: Survey evidence from northern area of Pakistan. Energy Reports, 3, 54–60. doi:10.1016/j.egyr.2017.03.002.

[73] Alsabbagh, M. (2019). Public perception toward residential solar panels in Bahrain. Energy Reports, 5, 253–261. doi:10.1016/j.egyr.2019.02.002.

# Appendix I

***Questioner for Adoption of Solar Systems***

| | |
|---|---|
| **Demographics** | 1. What is your Country?<br>2. What is your Area?<br>3. Please indicate your willingness to install and pay for solar equipment?<br>4. Please indicate (Yes/No) your possibility of using solar-generated electricity if the price is the same as fossil fuel-generated electricity.<br>5. Type of solar equipment in use.<br>6. Duration of solar use.<br>7. Your Gender?<br>8. Your Age?<br>9. Qualification Level? |
| 7- Extremely Agree, 6- Quite Agree, 5- Slightly Agree, 4- Neutral, 3- Slightly Disagree, 2- Quite Disagree, 1- Extremely Disagree | |
| **Perceived Usefulness** | 10. Using solar equipment for my electricity needs enables me to accomplish more tasks more quickly.<br>11. Using solar equipment for my electricity needs increases my productivity.<br>12. Using solar equipment makes it easier to do my work/job.<br>13. Overall, solar equipment for electricity needs is advantageous.<br>14. Using solar equipment for my power/electricity needs improves my home and business. |
| **Compatibility** | 15. The solar equipment is compatible with my requirements of that electricity-type.<br>16. The solar equipment fits well in successfully providing the amount of that electricity-type I need.<br>17. The geographic and environmental conditions at my home location are suitable for/compatible with my choice of solar equipment.<br>18. Using solar equipment fits my lifestyle. |
| **Ease of Use** | 19. Setting up of solar equipment is challenging.<br>20. Understanding to use solar equipment is easy.<br>21. Easy to use solar equipment is important for me.<br>22. I am adequately skilled to use solar equipment. |
| **Observability** | 23. I have observed how others use their solar equipment<br>24. In my society, one sees solar equipment in many houses.<br>25. I have seen solar equipment in use outside my society.<br>26. It is easy to observe others, who use solar equipment in my society. |
| **Perceived Trust** | 27. Using solar equipment meets my electricity needs 24/7.<br>28. Using solar equipment ensures reliable electricity supply.<br>29. Electricity/power generated using solar equipment cannot be stolen.<br>30. With solar equipment, I am sure no one will give me a wrong electricity bill. |
| **Attitude** | 31. I find solar equipment to be a major source of electricity in future.<br>32. I believe it is good (or right time) to use solar equipment in my house.<br>33. I like the idea of using solar equipment as a source of electricity in my house.<br>34. Overall, I think I will enjoy solar equipment as a source of electricity in my house. |
| **Behavioral Intention** | 35. I will continue using the solar equipment.<br>36. My willingness to remain using solar equipment is high.<br>37. I want to carry on using solar equipment.<br>38. The possibility of me continuing using solar equipment is high. |
| **Actual Use** | 39. On average, how frequently do you use solar equipment as a source of electricity?<br>40. On the average working day, how much time do you use solar equipment as a source of electricity? |