Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-023-27928-9

RESEARCH ARTICLE

Evaluating the environmental impact and economic practicability of solar home lighting systems: a roadmap towards clean energy for ecological sustainability

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Received: 16 March 2023 / Accepted: 22 May 2023

Abstract
The vitality contribution is a vital cause for defensible monetary improvement and collective success by eradicating poverty. Adopting the solar home lighting system (SHLS) is advantageous not only in social lifestyles but also improves the health of family members and increases home-based small businesses activities due to the inexpensive and continuous supply of energy. The main aims of the study are to scrutinize the most substantial barriers to adopting SHLS in Pakistan. A comprehensive, structured questionnaire appraisal was conducted for sample size with the help of non-probability sampling (purposive sampling), and primary data was collected. The designated hypotheses were evaluated using partial least square structural equation modeling (PLS-SEM). In the present study, we validate the model using a sample of 271 adopters of SHLS contributed as respondents. The results disclose that entire autonomous variables expressively and positively correlated with adopting SHLS dipping energy disasters and improving home-based small business activities. Correspondingly, social media-based awareness of SHLS significantly moderates and positively affects the selected factors in this study. Empirical results indicate that prudently eradicating maintenance barriers with experienced professionals, subsidy in prices from the government, quality base satisfaction of owners, and social media-based awareness are the primary tools to adopt SHLS. Additionally, the outcomes offer valuable suggestions to the competent authorities that introduce encouragement and maintenance policy for adopting SHLS.

Keywords Renewable energy · Solar home lighting systems · Prospective and barriers · Sustainable energy supply · Social media · Rural electrification · Economic viability · Pakistan

Responsible Editor: Roula Inglesi-Lotz

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Introduction

Renewable energy options mitigate environmental issues and provide lasting solutions to such energy issues (Govender et al. 2019; Xin et al. 2022). Energy has been established by the fundamental needs of current life (Elfaki et al. 2022; Umar et al. 2021). As a result of growing industrialization, energy consumption is rising, followed by higher expenses, enhanced profitable growth, and improved living conditions (Hall and Klitgaard 2018). A dependable energy supply is crucial for economic growth (Oyeleke and Akinlo 2019). An imbalance between energy demand and supply hinders economic development, prosperity, and sustainable growth and severely affects a country's water resources, environment, human health, and agricultural output (Jha and Schmidt 2021). Spans of unregulated electrical ultimatum and source openings have afflicted the country (Kennedy et al. 2019). Despite daily increases in energy demand and use, most of

Published online: 01 June 2023

the world's energy is still derived from fossil fuels. There are inadequate sources of fossil fuels to meet demand, and the volatility of their prices harms the global economy (Adebayo 2023a; Tian et al. 2021). In the global south, 250 million people still rely on traditional energy sources for heating, cooling, lighting, and other daily requirements (Silva et al. 2022). Increased reliance on or excessive use of fossil fuels and wood as fuels substantially influences the ozone layer. It enhances carbon emissions, sulfur dioxide, and environmentally toxic pollutants. However, crude oil hurts the atmosphere and provides most of the world's energy. Pakistan, similar to the respite of the emerging world, desires substantial energy to support its population and production (Mukherji et al. 2020). The alternative energy influence on energy desires is around 0.5%, which is negligible (NEPRA 2021). By the end of May 2021, Pakistan's nationwide vitality mix for the financial year 2019–2020 is 121,691 GWh, through thermal plants secretarial for 57% of energy production, hydroelectric plants accounting for 32%, alternative energy accounting for 3%, and nuclear plants accounting for 8% (NEPRA 2021).

Solar isolation (5.5 Wh m^{-2} d^{-1}) and yearly sources of sunshine length of 8–10 h d^{-1} benefit Pakistan. In the coastal regions of Sindh and Baluchistan, wind swiftness range from 5 to 7 m/s, and the wind drive prospective spreads 20,000 MW. In Southern Punjab, Sindh, and Baluchistan, the average intensity of solar radiation ranges from 1500 to 2750 W/m^2 per day, with a daily duration of 10 h. Pakistan's monthly energy production per square meter must be between 45 and 83 MW (Ali et al. 2021). Fortunately, Pakistan's geographic locations offer substantial perspective (around 81 shedload tonnes per annum) for entirely alternative energy sources, counting bioenergy, solar, and wind (Kurata et al. 2018). The influence of contemporary know-how on the nation's defensible monetary development is substantial (Adebayo 2023b). Sixteen to 18 h daily in rural areas and 10 to 12 h per day in urban municipalities without power in Pakistan. Around 51 gazillion people in Pakistan face an energy deficiency, and 50% of the inhabitants are deprived of hygienic gastronomic conveniences (IRENA 2020). Pakistan's connected energy generation dimensions touched 34,501 MW in May 2021. It is expected to upsurge by 53,315 MW by 2030 (NEPRA 2021).

This study models the adoption of solar home lighting system (SHLS) technology in Pakistan to examine the moderating effect of social media-based technological awareness. We have talked with locals about the significant difficulties of accepting SHLS nationwide. In this study, respondents were designated by applying a snowball sampling method. Using measurable statistics assortment methods, opinion-poll were exploited to attain the evidence mandatory to complete the research objectives. PLS-SEM was employed to estimate the composed facts. The results indicate that Pakistan's thorough removal of financial and legislative fences encourages investors to use SHLS substantially. The study suggests that to promote SHLS, the government should adopt an economic policy based on social media awareness for owner training and eliminating maintenance barriers with experienced personnel.

The controlling establishments must arrange the use of SHL and entice outlay. This study explored the technological obstacles and major societal influences hindering the widespread implementation of SHLS in Pakistan. Present societal performance is connected to discrete conduct, the cause of common niches. The incentives for solar energy users to adopt SHLS are outlined in Table 1. The current research model explores the impact of methodological social media-based awareness on the intention to adopt SHLS in the country. In the present investigation, respondents were nominated utilizing a purposeful selection method. Surveys continued to be employed to attain the necessary data to accomplish the research objectives, utilizing measurable statistics collection methods. The results suggest that the government of Pakistan has relinquished its financial and maintenance responsibilities to encourage residents to install SHL structures in a significant and productive manner. The study suggests that to expand SHLS, the government should design user efficiency, increase social media-based awareness, consider environmental concerns, and eliminate maintenance bottlenecks. Utilization of SHLS is a top priority for

Table 1 Motivation to adopt SHLS for residential using different influences

Justifications	Situations (%)	Reaction (%)	Occurrence
Social status	36	14	23
Redeemable-energy	41	17	19
Remunerations for time-saving	33	14	21
Health compensations	21	09	14
Eco-friendly rewards	23	10	14
Inaccessibility of substitute energies	24	13	19
Subsidy	47	18	21
Motivation by existing solar home lighting	46	19	26
Motivation by production organization	35	16	23

the oversight organization. The current study examined the practical challenges and significant environmental factors the nation must avoid after implementing SHLS. It is the cause of public function that contemporary societal functions are interdependent.

The reasons why residents are interested in SHLS are outlined in Table 1. Therefore, numerous obstacles and substantial concerns impede the nation from adopting solar residential lighting. This study aims to categorize the most significant hurdles and why residents forego SHL. Solar lighting is not yet socially acceptable in Pakistan, regardless of its monetary paybacks, technological practicality, and ecological compensations. The prevailing examination has revealed a substantial facts fissure regarding main contributory factors, such as market, institutional, and household fuel source choices. Adopting an SHLS has adverse effects on the collecting period and firewood costs but significantly promising effects on residents' prosperity and income (GoP 2020).

To address this study gap, we used the model with social media-based awareness moderation to assess SHLS adoption from a philanthropic standpoint. Experts on environmental deeds assert that unique norms are encouraged. Due to the inconclusive nature of the study, it was required to investigate an additional variable as a moderator to improve pro-environmental behavior. Using social media-based awareness as a moderating variable, we analyze the predictive impact of the relationship between an individual's values and more excellent good behavior. According to experimental investigations, social media-based awareness is becoming increasingly significant for eco-conscious behavior (Adebayo et al. 2023; Mahmood et al. 2021). The internet, social networking sites, and mobile device technology have matured into vital and beneficial global transmission tools. Prior study has studied the significance of social media for a variety of public attitudes, such as a more sustainable method of shopping, a desire to recycle and a commitment to environmental responsibility, and a reduction in fast food consumption (Bao and Shang 2021; Kumar 2021). In Pakistan, where there are approximately 73.5 million internet users and 35.3 million Facebook profiles, the literature lacks an up-to-date understanding of the adoption of a social media aspect and technology for creating SHLS, especially in the context of Pakistan, where there are 35.3 million Facebook profiles. The moderating effect of social media-based knowledge on awareness of SHLS, perceived user efficiency, perceived environmental concern, financial and maintenance government responsibility, and investment in SHL technology is investigated (Ali et al. 2022a).

All prior research on the energy sector in Pakistan (Arshad et al. 2018; Iqbal et al. 2018; Sun et al. 2022) has focused on the mandate and source-based power opening, vitality-producing foundations, the forthcoming of the power subdivision, the valuation of the vitality segment in the state, and the vitality combination. Irrespective of the preceding investigator's long-lasting attention, each of the present researches has explicit openings: the absence of procedural barriers examination and serious societal influences on implementing SHLS depress financiers and all sorts of outlay; and economic scheduling for understanding the financial paybacks of SHLS. This study will explore the primary obstacles and heavy influences of SHLS for the supportable expansion of SHL in Pakistan; highlight the connecting and working barriers for the removal of these obstacles to attracting SHLS residents for the sustainable development of SHLS; and empirically the study of solar panel energy evaluates the moderating role of social media-based awareness of SHLS for the sustainable development of SHL. The results of this study will help administration institutes, experienced establishments, and private organizations streamline the extravagant process. Solar lighting for rural people is designed to generate renewable energy cheaply, reducing greenhouse gas emissions.

Moreover, the current study intends to teach residents about the paybacks of accepting SHLS, develop their capabilities, and improve their installations because of the little initial outlay and long-standing returns. This research aims to decrease monetary hazards, eliminate investing barriers of SHLS, produce cost-free energy via small-scale SHLS for self-consumption by local inhabitants, and increase SHLS competencies. In addition, this study intends to ensure coordination between information institutes, administration entities, and metropolises within the solar occupational. Subsequently, the primary purpose of this study was to analyze and clarify the primary factors that discourage locals from adopting SHLS. This study aims to persuade local investors to engage in SHLS for sustainable solar energy development by revealing Pakistan's solar potential. This study aims to investigate the essential characteristics of SHLS in Pakistan for the further development of solar technology. The hypotheses include social media-based awareness of SHLS (SMBA), maintenance barriers of SHLS (MB), technician's availability for SHLS (TA), the economic viability of SHLS (EV), and level of owner's satisfaction with SHLS (LOOS). As a result, residents' living standards are high due to low-cost energy. The following section investigates research design and formulation hypotheses, conceptual models, and research methodologies. Hypothesis testing is covered under the data analysis and results section, and the discussion covers the study's findings, implications, conclusion, and critical limitations.

Formulation of hypotheses through hypothetical circumstantial

Maintenance barriers of solar home lighting system

The improvement of solar expertise in pastoral zones of Pakistan founds its supremacy over vitality verdicts to improve the financial complications instigated by energy incompetence. Investigating the durables controlling vitality effectiveness and the significance of solar machinery needs domination. Solar vitality is a viable renewable energy source with huge potential for sustaining the country's energy and economic requirements. Solar energy is the most notable breakthrough for creating energy worldwide from various electrons and elements (Kawabata et al. 2020). Europe estimates worldwide solar energy dimensions will range from 900 GW near the ground by the end of 2021 and 971 GW below the elevation structure. Fortunately, Pakistan's geographic location affords excellent opportunities for 81 million tonnes of alternative energy foundations per year, including wind, solar, and bioenergy. Nationwide, the country has a solar isolation of 5.5 Wh m^{-2} d^{-1} and yearly sources of daylight interval of 8–10 h d^{-1} (Ali et al. 2021). Due to its summer sessional character, Pakistan has many solar resources based on hot weather. In rural locations, successfully utilizing these solar resources might generate fruitful outcomes. Utilizing hot-weather and sunny solar resources can minimize emissions and increase economic benefits (Adebayo 2023c; Sun et al. 2021). The SHLS generates electricity, reduces conservatory fume radiations, stimulates monetary growth by increasing revenues, and their modernization can improve ecological enactment. Pakistan has an estimated solar energy potential of over 1600 GW, which, if appropriately utilized, could meet the nation's energy needs (Rafique et al. 2020)—accepting SHL expertise in pastoral areas can significantly assist the state's financial development. Its similar condition accurately portrayed the solar approval of sites and projected monetary growth (Ali et al. 2022b). Based on these results, we first proposed the following hypothesis:

H1: Maintenance barriers of solar home lighting systems have an optimistic association with adopting solar home lighting systems.

Technician's availability for solar home lighting systems

The solar energy industry faces specific obstacles that must be overcome to effectively and efficiently produce solar megaprojects. The most significant obstacles to the initial cost of solar home lighting energy projects can provide investors with long-term financial benefits; from this standpoint, SHLS is the best energy source (Jan 2021). SHLS is an independent photovoltaic vitality scheme that offers remote off-grid households an economical method of providing a huge volume of energy for miscellaneous applications such as lights. In pastoral zones where the electrical gridiron is still powerless to influence, SHLS can be utilized to meet domestic vitality needs, meeting basic electronic requirements. In rural Pakistan, solar lighting technology has come to dominate energy choices to combat the monetary conditions attributed to energy inefficiencies (Ali et al. 2022a). Analyzing the long-term dominance in energy efficiency and the implications of solar technology for long-term reserves necessitates dominance. The nation needs qualified SHLS experts. The administration has abundant solar possessions, counting hot weather and the most significant number of sunny days yearly. The SHLS is required globally to increase prosperity and alter the economic standing of rural populations (Adebayo and Alola 2023; Barman et al. 2017). SHLSs generate affordable energy because power can be obtained for free by installing solar panels to meet energy needs (Ali et al. 2022d). The rooftop SHLS system can reduce energy costs. The per-unit cost for rooftop SHLS is approximately $0.211, and there are no longer any additional fuel costs. SHLS installed on rooftops can generate income within a few years. Worldwide studies support the installation of SHLS to upsurge the energy source for pastoral zones at a low-slung cost, which is a substantial experiment (SAARC 2020). We formulated the following second hypothesis in light of these findings:

H2: Technician's availability for SHLS has an optimistic association with adopting solar home lighting systems.

Economic viability of solar home lighting systems

Approximately 67% of the inhabitants of Pakistan reside in pastoral areas and need commercial and residential energy bases. Prevailing moveable SHLS are advantageous because of their high energy productivity, little cost, transparent strategy, and movability. This kind of SHLS can contribute to the growth of pastoral zones and meet housing demands (Ali et al. 2019). SHLS is an eye-catching energy basis for industry holders who engage in additional revenue-generating actions, such as operating a mobile phone or mobile-arraigning business. SHLS can increase energy access and decrease Bangladesh's reliance on relic energies. The connected SHS helps reduce energy expenses and carbon dioxide releases (Adetona and Ogunyemi 2020; Adewale and Sunday 2023). The adoption of SHLS correlates with rural community prosperity. Solar energy development consists of household energy digesters and SHLS for power production, extensive SHLS, and small solar digesters in stony zones: the encouragements, processed solar incorporation, the construction of numerous funds outlay mechanisms, and solar sector enhancement (Irfan et al. 2023; Mandal et al. 2018). These results are consistent with

Pakistan's initiative to paradigm solar conveniences. This significance clarifies the importance of solar energy for individual investment and its connection to economic expansion. In rural areas, the efficient use of SHLS can produce economic growth that surpasses the limits of SHLS implementation. From the standpoint of an expert organization part, solar energy is the best alternative energy option for the region's growth and success. Besides providing societal, monetary, and conservational benefits, profitable SHLS is viewed as the upcoming of pastoral societies (Yadav and Shankar 2019; Zang et al. 2023). Overall, the theoretical model of this study benefits Pakistan's SHLS challenges and pastoral success. These considerations guide the construction of the third assumption stated below.

H3: Economic viability of SHLS has an optimistic association with the adoption of solar home lighting systems.

Level of owner's satisfaction with solar home lighting quality

Recently, solar energy has been incorporated into small business operations. The sun provides a renewable solar energy source (Luyer et al. 2021). Using SHL panels to produce vitality can reduce drive outages and solve Pakistan's environmental issues. SHLS are the most effective energy sources and indispensable elements for a sustainable transition. Enhanced utilization of these possessions for energy construction can decrease the country's CO2 discharges. The research study by Opiyo (2019) demonstrates the benefits of SHLS for small business operations. This study suggests that SHLS generates electricity or heat to power low-voltage appliances. After installing an SHLS, no daily or monthly payments are required. Therefore, the vitality produced by an SHLS is inexpensive, and the currency protected can be applied elsewhere in the trade. When the personnel of small company operations have a stronger grasp of SHLS, they can purchase higher-quality solar panels, which produce more energy at a cheaper cost, are inexpensive to install and maintain, and have solar energy storage systems (Abdullah et al. 2017). It improves people's existing morals and may also positively distress their survival. The application of Pakistan's SHLS perspective is indispensable for financial development. SHLS must be implemented in all rural regions of the USA (Jan and Akram 2018). Because of the semi-immobile connection price of the SHLS, the benefits obtained in subsequent years surpass those of the initial time. Using hot weather to establish an SHLS in Pakistan with solar radiation manure is feasible, according to a cost–benefit analysis. The fourth hypothesis was presented in light of the following findings:

H4: The level of owner's satisfaction with solar home lighting quality has an optimistic association with the adoption of solar home lighting systems.

The moderating role of social media-based awareness between maintenance barriers of SHLS and the adoption of SHLS in Pakistan

Literature reveals conflicts in the relationship between personal values and climate behavior, requiring incorporating external variables (Joshi et al. 2021). The research utilizes media platforms to comprehend improved relationships between environmentally conscious behavior and individual consumer responsibility towards the environment and SHLS. The audience receives accurate and credible environmental education content from the media (Amit Kumar 2021). The value of social media for connecting, expressing interest, and learning about current events is increasing. It connects individuals globally, allowing them to comprehend what is occurring where. The expansion of social media influences individual interests and resident conduct (Mufidah et al. 2018). Social groupings' justifications or explanations for green and SHLS consumption motivate others to do the same. With social media-based awareness, the general public can immediately see the effects of eco-friendly actions, encouraging others to engage in such activities. In addition, it has been demonstrated that media platforms can more effectively compare psychological with self-accomplishment, encouraging climate behavior (Esteves et al. 2021; Grigoryan et al. 2022; Han and Xu 2020). It was discovered that media outlets influence residents' attitudes and behaviors regarding numerous environmental issues, such as greenhouse gas emissions, energy shortages through SHLS, and environmental degradation (Sreen et al. 2021). While broadcasting is becoming an increasingly popular and effective medium for linear movements, its efficacy in implementing climate improvements, climate security activities, and environmental legislation is still under investigation (Bretter et al. 2022; Valdez et al. 2017). Recent research shows that social media awareness modifies environmentally responsible behavior for SHLS. Given the preceding reasoning, it is reasonable to assume the fourth hypothesis:

Hypothesis 5 (H5): Solar home lighting's social media-based awareness positively moderates the association between stem's maintenance system's maintenance barriers.

Hypothesis 6 (H6): Solar home lighting's social media-based awareness positively moderates the association between technicians' availability of solar home lighting systems and the adoption of SHLS in Pakistan.

Hypothesis 7 (H7): Solar home lighting's social media-based awareness positively moderates the association between the economic viability of solar home lighting systems and the adoption of SHLS in Pakistan.

Hypothesis 8 (H8): Solar home lighting's social media-based awareness confidently moderates the connotation between the owner's gratification with solar home lighting quality and the adoption of SHLS in Pakistan.

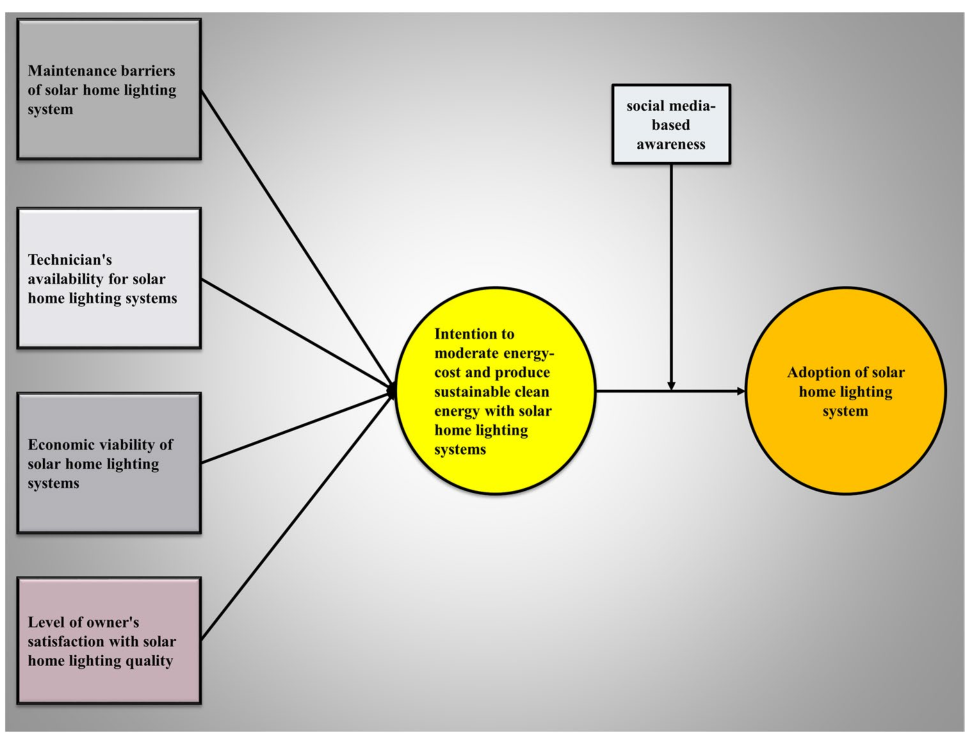
Hypothesis 9 (H9): There is an association between social media-based awareness and the adoption of SHLS in Pakistan.

In this paper, the philosophy supports the vitality assortment assumption. This study spread the impression of vitality selection to a specific matter. Provisional on the obtainability of solar lighting influences in regions where it is feasible to attach fume, the study will determine whether solar lighting is an alternative energy source. Every domestic can select a specific energy rendering to the vitality ranking standard. For many nations researching new renewable energy bases, assembling the hygienic vitality needs of their populations with conservative energy bases presents a challenge. This concept includes two indispensable mechanisms: financial and treasure (Ozoh et al. 2018; Wu et al. 2021). Using a theoretical framework, this research was directed in Pakistan to examine the variables manipulating the implementation of SHLS. Environmental, social, and technological factors cannot be ruled out as causes of the disappointment or achievement of SHLS with residents or civilization. The psychological example depicted in Fig. 1 may inspire a resident's assortment of alive vitality basis. The theoretical prototypical illustrates the predictability of the relationship between the self-influential adjustable and the reliance flexible. Furthermore, the proposed prototypical depicts the projected moderation amid the independent variable (IV) and the dependent variable (DV).

Material and methods

This study utilized snowball sampling kind of non-probability sampling with questionnaires to evaluate the prospective of SHLS in Pakistan and improve prevailing solar energy facilities. Non-probability sampling methods consist of quota sampling, snowball sampling, purposive sampling, voluntary response sampling, and convenience sampling, and the snowball sampling method did not provide an equal opportunity for all inhabitant's followers to contribute to the research. The current sampling method is utilized for exact inhabitants' physiognomies, experimental research, qualitative study, and experimental study. Active SHLS were designated for study to improve their facility and superiority. Employing the snowball sampling method, a demonstrative taster of SHLS from across the nation was collected, with specific SHLS as the starting point. To achieve this objective, researchers in Pakistan polled from September to November 2022 faced a significant challenge in reaching relevant respondents (residents). In addition, snowball sampling was used to select Pakistani respondents who exhibited various behaviors for this study. When randomization

Fig. 1 Theoretical framework



is unavailable and participants are known to one another, snowball sampling is inadequate for oversimplification of the hypothesis (Ozoh et al. 2018).

The current objective of the research is to investigate the opportunities and limitations of adopting SHLS and to evaluate the monetary enactment of happy SHLS owners. The moderating effect of consciousness and comprehension on accepting SHLS is among the gratification connection and reduces barriers. This study used opinion-poll to collect respondents' evidence per a measurable methodology. Our research analyzed data using structural equation modeling (SEM) (Ali et al. 2022b). Because it is a constituent-focused method, it explored the association measurements (Urbach and Ahlemann 2010). The extensive use of PLS-SEM in subsequent studies is evidence of its power; this study's author also employed it (Ying et al. 2020). Conservative arithmetic investigation techniques are inferior to structural equation modeling (SEM). It is helpful for statistically analyzing a product's efficacy, suitability, and accuracy (Franziska et al. 2016). Despite being an additional age group technique, SEM discourses the problems associated with leading peer-group investigation. Because SEM is a multivariate examination technique, it can be used to evaluate multiple factors simultaneously.

SEM is predominant in occupational study because of its capacity to manage complex and multiple connections simultaneously (Chin and Newsted 1999). Variance-based SEM (VB-SEM) or partial least square (PLS)-SEM and covariance-based SEM (CB) are established SEM methods (Henseler et al. 2009). Inappropriate use of investigative events might consequence in inaccurate conclusions. For management and societal discipline exploration, on the other hand, a suitable statistical method is of extreme standing (Ramayah et al. 2010). PLS-measurement SEM and structural prototypical are binary phase logical measures that comprise dimension consequences (Osborne et al. 2010). Using measurement analysis, convergent validity was evaluated with the average variance extracted (AVE), interior uniformity dependability was restrained about composite reliability (C.R.), and element dependability was dignified concerning external stuffing. The evaluation of consistency, rationality, and the internal prototype are incorporated into the measurement assessment model. The structural assessment model includes evaluating the outer model and testing suppositions/interactions. The current research has used PLS 3.0 software for the main statistics examination to investigate the relationships between the adjustable lower than consideration. In addition, partial least square path modeling provides greater arithmetical influence than covariance-based structural equation modeling. PLS-SEM is extra beneficial for detecting variable associations.

Sample and procedure

We were successful in reaching 321 relevant respondents. Two hundred eighty-seven (287) respondents agreed to contribute to the survey. Subsequently getting approval from respondents, researchers physically distributed open- and closed-ended opinion polls to every respondent via LinkedIn and WhatsApp. Two hundred seventy-three questionnaires were received in their entirety for the questionnaire investigation. The reaction proportion was 90.94%, but 26 surveys were eliminated due to unmatched and insufficient responses. Two hundred sixty-one valid responses were obtained from the sample for study analysis. Respondents provided their personal information in response to the presence of investigators and groups in the research zone. A detailed description of the sample supports the conclusion. The demographic physiognomies of the respondents, such as stage, capability, schooling, and sexual category, also reveal the diverse circumstances of those who provided the correct response in the current research (see Table 2). Moreover, every representative has a complete understanding of SHLS and demographic dimensions. The first section of the opinion poll is devoted to the respondents' statistics, although the subsequent section focuses on SHLS's characteristics. Existing SHLS were chosen for research to improve their quality and service.

In the current research, the investigators have incorporated all fundamentals from previous research. The study led to the development of products based on the repair obstacles

Table 2 Demographic profile of respondents (*N* = 261)

Variables	Features	Frequency	%
Gender	Male	229	87.73
	Female	32	12.26
Age	Less than 26	73	27.96
	25–40	61	23.37
	41–55	51	19.54
	56–65	43	16.47
	65 and above	33	12.64
Education	Metric	81	31.03
	Faculty of arts	74	28.35
	Bachelor	57	21.83
	Master	49	18.77
Experience	0–5 years	78	29.88
	6–10 years	86	32.95
	11–15 years	54	20.68
	16–20 years	43	16.47
Brand	Trina solar TSM	83	31.80
	Sun power × 22	66	25.28
	Ja solar MR series	57	21.83
	Hanwha Q cell Speak Duo	55	21.07

of solar home lighting systems (Barman et al. 2017). The study's findings regarding the technician's availability for solar home lighting systems were adopted (Ali et al. 2022c). Assumed factors related to the economic viability of solar home lighting systems (Ali et al. 2022a). Elements about homeowner satisfaction with solar home lighting quality were developed (Ali et al. 2022d). Adopted items comprise the social media-based awareness of adopting SHLS (Wang et al. 2020). Finally, this study adopted items related to the adoption of SHLS (Hair et al. 2014).

Demographic profile of respondents

Most respondents fall in the male category, with 229 (87.73%), while females were around 32 (12.26%). In addition, the young respondents aged less than 26 were 73 (27.96%), respondents aged 25–40 were 61 (23.37%), and 41–55-year-old respondents were 51 (19.54%) in the majority from all age ranges, followed by respondents aged 56–65 years who were 43 (16.47%) and respondents aged above 65 who were in low quantity (33, 12.64%). On the other hand, 81 (31.03%) respondents belong to metric education below the secondary level, which is the lowest. We also go through their experience; respondents with experience below 5 years were 78 (29.88%), while a majority of them had 6–10 years (86 (32.95%)), but some respondents have 11–15 years of experience ranging from 54 (20.68%), and finally, some respondent followed by 16–20 years old 43 (16.47%). According to brand adoption, there were 83 (31.80%) respondents with Trina solar TSM brand, 66 (25.28%) respondents with Sun power, 57 (21.83%) had adopted Ja solar MR series, and 55 (21.07%) respondents with Hanwha Q cell Speak Duo solar brand. Statistics are shown in Table 3.

Data examination and outcomes

All validated rationality and consistency values for this measurement model are provided in the following tables. All influence stuffing values are more significant than 0.5, and entirely elements' convergent rationality in the measurement valuation model is effective. The direction investigation has been demonstrated to evaluate the assumptions, and the findings indicate that TA (SHLS), EV (SHLS), and IMESCE (SHLS) are positive. On the other hand, LOOS (SHLS) negatively affects ASHLS and accepts EV (SHLS), IMESCE (SHLS), TA (SHLS), and SMBA. In addition, the data indicate that SMBA moderates the relationships among EV (SHLS), IMESCE (SHLS), TA (SHLS), LOOS (SHLS), and MB (SHLS) and accepts EV (SHLS), IMESCE (SHLS), TA (SHLS), and LOOS (SHLS) but not accepted to MB (SHLS). Moreover, the data also indicate that IMESCE (SHLS) significantly mediates the relationships among EV (SHLS), TA (SHLS), LOOS (SHLS), SMBA, and MB (SHLS) and accepts these all except MB (SHLS). This segment explores convergent rationality, which establishes the association between items. Table 2 results and connections demonstrate that the loadings and AVE values are more significant than 0.50, whereas the alpha and composite reliability (C.R.) values are more significant than 0.70. These numbers imply that convergent validity is a good and substantial relationship between the items. AVE values exceed 0.50, and composite reliability (C.R.) values surpass 0.70. These numbers suggest a high degree of item correlation and valid convergent validity.

Measurement assessment model

The measurement model validates the constructs' reliability and validity, and the model authenticates all item factor loadings (Hair et al. 2019). Figure 2 of the measurement assessment model displays the variable factor loadings. The measurement assessment model is consistent across dependability, and rationality assessments, convergent rationality, and discriminant legitimacy, respectively (Hair et al. 2011). Entirely element loadings exceed the criterion value of 0.5 (Hair et al. 2014) (Table 2). Every normal influence stuffing was more than 0.50, and each observation contributed to the produced variable, as confirmed by the research's investigation (Arbuckle 2011). AVE above the suggested value of 0.5. The composite reliability rating for each standard is more significant than 0.70, demonstrating that the dimensions are trustworthy (Anderson and Gerbing 1988). AVE values range between 0.588 (social media-based awareness) and 0.865 (maintenance barriers of solar home lighting systems), while C.R. values range between 0.892 (adoption of solar home lighting systems) and 0.981 (maintenance barriers of solar home lighting systems). All supplementary stuffing has standards between 0.5 and 0.947 within $N=261$.

Due to several studies criticizing the Fornell-Larcker standard, the heterotrait-monotrait proportion of connections (HTMT) is observed as a more appropriate discriminant rationality quantity (Wang et al. 2020). If the value of discriminant rationality is less than 0.85 (Cohen 1988) or 0.90, it is confirmed (Irfan et al. 2021). Moreover, Table 4 of the results segment displays the discriminant cogency using Fornell-Larcker on the relationship between the variables. In Table 5, all values are less than 0.90. The consequences segment has also demonstrated the discriminant rationality of the variables' interconnection. The variable standards imply that the standards indicating an association with the adjustable itself are larger than those representing a relationship with additional adjustable. This study also employed the HTMT ratio to analyze the relationship

Table 3 Convergent validity examination

Constructs	Items	Loadings	C.B alpha	C.R	AVE
Maintenance barriers of solar home lighting systems	MB (SHLS)1	0.925	0.978	0.981	0.865
	MB (SHLS)2	0.941			
	MB (SHLS)3	0.929			
	MB (SHLS)4	0.935			
	MB (SHLS)5	0.938			
	MB (SHLS)6	0.922			
	MB (SHLS)7	0.931			
	MB (SHLS)8	0.921			
Technician's availability for solar home lighting systems	TA (SHLS)1	0.945	0.959	0.967	0.832
	TA (SHLS)2	0.843			
	TA (SHLS)3	0.944			
	TA (SHLS)4	0.947			
	TA (SHLS)5	0.842			
Economic viability of solar home lighting systems	EV (SHLS)1	0.843	0.894	0.922	0.703
	EV (SHLS)2	0.874			
	EV (SHLS)3	0.755			
	EV (SHLS)4	0.841			
	EV (SHLS)5	0.874			
Level of owner's satisfaction with solar home lighting quality	LOOS (SHLS)1	0.857	0.899	0.929	0.766
	LOOS (SHLS)2	0.880			
	LOOS (SHLS)3	0.885			
	LOOS (SHLS)4	0.880			
Social media-based awareness	SMBA1	0.773	0.889	0.909	0.588
	SMBA2	0.777			
	SMBA3	0.775			
	SMBA4	0.801			
	SMBA5	0.701			
	SMBA6	0.727			
	SMBA7	0.805			
Intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems	IMESCE (SHLS)1	0.879	0.907	0.935	0.782
	IMESCE (SHLS)2	0.860			
	IMESCE (SHLS)3	0.899			
	IMESCE (SHLS)4	0.899			
Adoption of solar home lighting systems	ASHLS1	0.873	0.819	0.892	0.735
	ASHLS2	0.881			
	ASHLS3	0.816			

N = 261; *ASHLS*, adoption of solar home lighting systems; *EV (SHLS)*, economic viability of solar home lighting systems; *IMESCE (SHLS)*, intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems; *LOOS (SHLS)*, level of owner's satisfaction with solar home lighting quality; *MB (SHLS)*, maintenance barriers of solar home lighting systems; *SMBA*, social media-based awareness; *TA (SHLS)*, technician's availability for solar home lighting systems

between factors. According to HTMT statistics, the values are less than 0.85. The research findings also evaluate the association between variables, known as discriminant rationality. Cross-loading was employed to evaluate the discriminant rationality. These standards suggest a short relationship between adjustable and validated discriminant rationality. Table 6 bold values indicate that the components have a strong affiliation, although other factors have feeble relationships. The highlighted standards examine the discriminant validity of the cross-loadings and are compared with supplementary apparatuses in every pillar. The variable standards imply that the standards indicating a relationship with the adjustable this one are greater than those indicating a relationship with other adjustable. These standards determine that discriminant rationality is a legitimate, weak association between variables (Table 7). Figure 2 depicts the measurement valuation

Fig. 2 Measurement model assessment

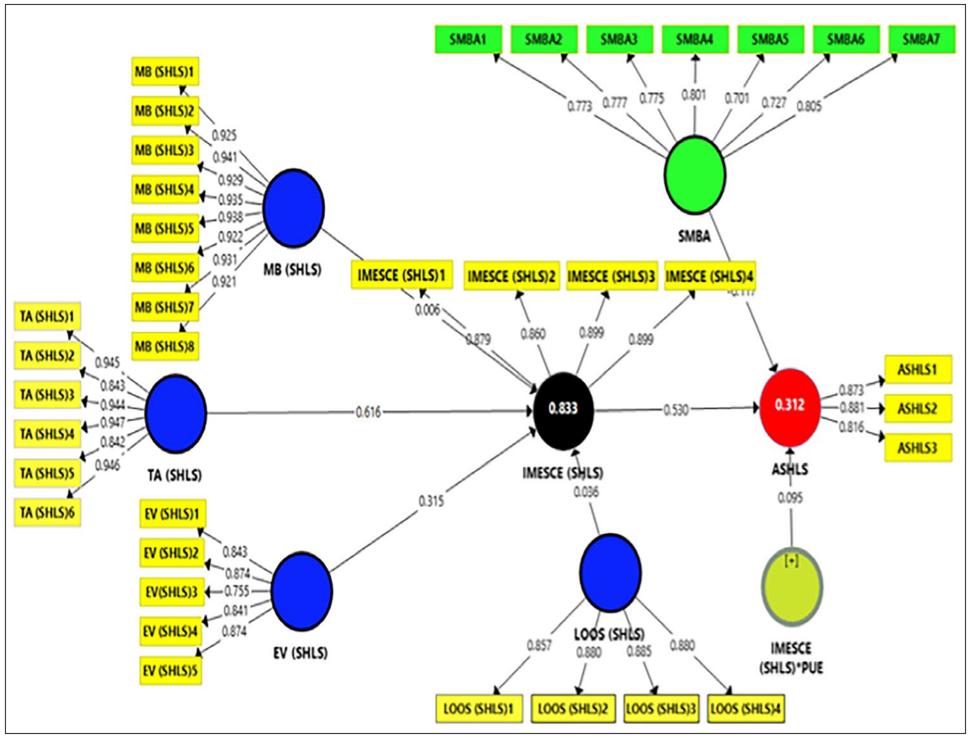


Table 4 Fornell-Larcker

S. no	Factors	ASHLS	EV (SHLS)	IMESCE (SHLS)	LOOS (SHLS)	MB (SHLS)	SMBA	TA (SHLS)
1	ASHLS	0.857						
2	EV (SHLS)	0.517	0.839					
3	IMESCE (SHLS)	0.536	0.841	0.884				
4	LOOS (SHLS)	0.391	0.412	0.401	0.875			
5	MB (SHLS)	0.479	0.496	0.486	0.408	0.930		
6	SMBA	0.140	0.054	0.030	0.113	0.136	0.767	
7	TA (SHLS)	0.516	0.824	0.893	0.377	0.501	0.024	0.912

Table 5 Discriminant validity analysis using heterotrait-monotrait ratio (HTMT)

S. no	Factors	ASHLS	EV (SHLS)	IMESCE (SHLS)	LOOS (SHLS)	MB (SHLS)	SMBA	TA (SHLS)
1	ASHLS							
2	EV (SHLS)	0.604						
3	IMESCE (SHLS)	0.622	0.931					
4	LOOS (SHLS)	0.453	0.457	0.441				
5	MB (SHLS)	0.535	0.528	0.516	0.435			
6	SMBA	0.138	0.084	0.073	0.118	0.130		
7	TA (SHLS)	0.580	0.887	0.870	0.399	0.515	0.052	

prototypical and indicates the variable factor loadings. All influence loading values are more substantial than 0.5, and all elements' convergent rationality in the measurement valuation model is effective.

Structural assessment model

The measuring model was evaluated first, then the structural assessment model, which investigated the relationship between exogenous and endogenous factors. The

Table 6 Cross-loading

Items	ASHLS	EV (SHLS)	IMESCE (SHLS)	LOOS (SHLS)	MB (SHLS)	SMBA	TA (SHLS)
ASHLS1	**0.873**	0.450	0.469	0.327	0.398	−0.064	0.492
ASHLS2	**0.881**	0.441	0.471	0.359	0.429	−0.149	0.447
ASHLS3	**0.816**	0.439	0.438	0.32	0.403	−0.147	0.385
EV (SHLS)1	0.427	**0.843**	0.660	0.332	0.386	−0.097	0.663
EV (SHLS)2	0.454	**0.874**	0.764	0.352	0.451	−0.020	0.732
EV (SHLS)4	0.429	**0.841**	0.657	0.334	0.38	−0.100	0.662
EV (SHLS)5	0.454	**0.874**	0.765	0.360	0.456	−0.020	0.725
EV (SHLS)3	0.402	**0.755**	0.666	0.350	0.398	0.001	0.666
IMESCE (SHLS)1	0.504	0.757	**0.879**	0.347	0.405	−0.077	0.740
IMESCE (SHLS)2	0.482	0.769	**0.860**	0.369	0.426	−0.016	0.794
IMESCE (SHLS)3	0.451	0.734	**0.899**	0.342	0.452	−0.033	0.788
IMESCE (SHLS)4	0.460	0.712	**0.899**	0.358	0.435	0.017	0.832
LOOS (SHLS)1	0.323	0.299	0.310	**0.857**	0.351	−0.094	0.295
LOOS (SHLS)2	0.341	0.382	0.362	**0.880**	0.354	−0.097	0.345
LOOS (SHLS)3	0.307	0.361	0.34	**0.885**	0.346	−0.106	0.309
LOOS (SHLS)4	0.392	0.392	0.384	**0.880**	0.376	−0.099	0.363
MB (SHLS)1	0.436	0.460	0.457	0.379	**0.925**	−0.158	0.466
MB (SHLS)2	0.443	0.468	0.445	0.400	**0.941**	−0.122	0.459
MB (SHLS)3	0.428	0.472	0.441	0.408	**0.929**	−0.12	0.452
MB (SHLS)4	0.442	0.466	0.465	0.375	**0.935**	−0.152	0.474
MB (SHLS)5	0.445	0.466	0.447	0.396	**0.938**	−0.117	0.464
MB (SHLS)6	0.466	0.452	0.450	0.354	**0.922**	−0.095	0.472
MB (SHLS)7	0.442	0.459	0.463	0.375	**0.931**	−0.149	0.470
MB (SHLS)8	0.461	0.449	0.447	0.351	**0.921**	−0.098	0.468
SMBA1	−0.102	−0.078	−0.019	−0.121	−0.085	**0.773**	0.001
SMBA2	−0.06	−0.038	−0.003	−0.081	−0.097	**0.777**	0.032
SMBA3	−0.103	0.009	0.021	−0.089	−0.076	**0.775**	0.052
SMBA4	−0.135	−0.052	−0.050	−0.131	−0.158	**0.801**	0.008
SMBA5	−0.009	0.057	0.085	−0.056	−0.070	**0.701**	0.093
SMBA6	−0.060	−0.006	0.035	−0.043	−0.050	**0.727**	0.049
SMBA7	−0.143	−0.069	−0.076	−0.047	−0.124	**0.805**	0.010
TA (SHLS)1	0.477	0.768	0.761	0.322	0.460	0.024	**0.945**
TA (SHLS)2	0.462	0.714	0.891	0.373	0.443	0.016	**0.843**
TA (SHLS)3	0.477	0.761	0.760	0.325	0.463	0.024	**0.944**
TA (SHLS)4	0.467	0.776	0.767	0.325	0.462	0.023	**0.947**
TA (SHLS)5	0.458	0.713	0.889	0.375	0.444	0.020	**0.842**
TA (SHLS)6	0.470	0.767	0.765	0.320	0.459	0.025	**0.946**

Table 7 Consequences of mediating effects through hypotheses evolution

Inconstant	*B* value	*T* value	*p* value	Judgments
EV (SHLS) → IMESCE (SHLS)	0.315	9.069	0.000	Accepted
IMESCE (SHLS) → ASHLS	0.530	11.249	0.000	Accepted
LOOS (SHLS) → IMESCE (SHLS)	0.036	1.296	0.099	Accepted
MB (SHLS) → IMESCE (SHLS)	0.006	0.210	0.417	Rejected
SMBA → ASHLS	−0.117	2.671	0.004	Accepted
TA (SHLS) → IMESCE (SHLS)	0.616	16.726	0.000	Accepted

structural model is evaluated using various statistical metrics, including impact size (f^2), t values, prognostic significance (Q^2), measurement of determination (R^2), and path constant (standards). Using PLS-SEM collected works criteria, the current study evaluates assumptions and calculates the significance of path coefficients. Using 5000 subsamples and a significance level of 5%, the bootstrapping method was exploited to control the connotation of the assumptions (one-tailed). The consequences disclose that all assumptions are acknowledged except H5. EV (SHLS) ($\beta = 0.315$, $t = 9.069 > 1.64$, $p < 0.05$), IMESCE (SHLS) ($\beta = 0.530$, $t = 11.249 < 1.64$, $p < 0.281$), intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems (moderator) ($\beta = 0.095$, $t = 2.050 > 1.64$, $p < 0.05$), LOOS (SHLS) ($\beta = 0.036$, $t = 1.296 > 1.64$, $p < 0.05$), MB (SHLS) ($\beta = 0.006$, $t = 0.210 < 1.64$, p 0.05), SMBA ($\beta = 0.117$, $t = 2.671 > 1.64$, $p < 0.05$), TA (SHLS) ($\beta = 0.616$, $t = 16.726 > 1.64$, $p < 0.05$), and intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems affect significantly and positively. All solar home lighting systems have significant positive results for adopting solar technology.

The R^2 worth for repair barriers of SHLS is 0.462, indicating that the prototypical has a substantial descriptive influence on the adoption of solar technology in Pakistan. Conversely, aiding a prototypical sole based on its R^2 value is not a viable and operative strategy. The model's Q^2 anticipated significance dimension is consequently the most precise. Indicating that the value of Q^2 exceeds zero, the dormant exogenous norms have an extreme prognostic significance, indicating that Q^2 is greater than zero. The consequences designate that the worth of Q^2 is 0.248, indicating that social media-based awareness can increase intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems and demonstrating the model's high predictive validity. These are the usual standards of f^2, counting 0.02, 0.15, and 0.35, which characterize small, moderate, and significant possessions in three categories, respectively. Therefore, the value of f^2 assumed that the effect size varies between moderate and large (see Table 8). Table 8 contains an assortment of arithmetical techniques. Because the T values are greater than zero, Fig. 3 depicts the structural valuation model, which suggests a significant association between the variables (1.64). In the structural assessment model for the adoption of SHLS in Pakistan, all moderated adjustable values are optimistic and demonstrate a significant association.

T values (1.64) are extra substantial than p values, so the structural valuation model represents the association between the adjustable. Solar technology contributes positively and significantly to the availability of technicians for SHLS in Pakistan. All moderated adjustable standards are suggestive of positive results. The structural assessment model for implementing solar technology in Pakistan to entice green FDI discloses a statistically significant relationship. We directed semi-structured interviews with uneducated SHLS holders (those incapables of completing the opinion poll) about the various operational aspects of SHLS to gain insight into the real concerns of SHLS holders. We applied knowledge about the repairs and operational barriers. Features comprise the maintenance cost of solar energy facilities, the availability of technicians, the initial investment cost, and the awareness of new technology. We conducted interviews with 53 SHLS owners from rural Pakistan. The parameters examined for SHLS and the responses (percentage) from SHLS owners are displayed in Tables 9 and 10. Each percentage reflects the distribution of responses collected from (illiterate) SHLS owners. The satisfaction and opinions of Pakistani respondents regarding their SHLS are displayed in Table 9. The primary reasons are the simplicity of the SHLS process, the obtainability of contrives and specialists, the monetary strategy paybacks, the fine assembly of light for kitchenette use, the utilization of light for lighting, and the progressive societal status. Nations in South Asia, such as India, Nepal, and Bangladesh, have adequate

Table 8 Structural model results through indirect effects and hypotheses analysis

	Hypothesis	B values	S.D	T values	p values	Supported	R^2	Q^2	f^2
H1	EV (SHLS) → IMESCE (SHLS)	0.315	0.035	9.069	0.000	Yes	0.466	0.248	0.071
H2	IMESCE (SHLS) → ASHLS	0.530	0.047	11.249	0.000	Yes		0.162	0.014
H3	IMESCE (SHLS)*PUE → ASHLS	0.095	0.046	2.05	0.021	Yes			0.113
H4	LOOS (SHLS) → IMESCE (SHLS)	0.036	0.028	1.296	0.099	Yes			0.102
H5	MB (SHLS) → IMESCE (SHLS)	0.006	0.030	0.210	0.417	No			0.007
H6	SMBA → ASHLS	−0.117	0.044	2.671	0.004	Yes			0.015
H7	TA (SHLS) → IMESCE (SHLS)	0.616	0.037	16.726	0.000	Yes	0.479		0.017

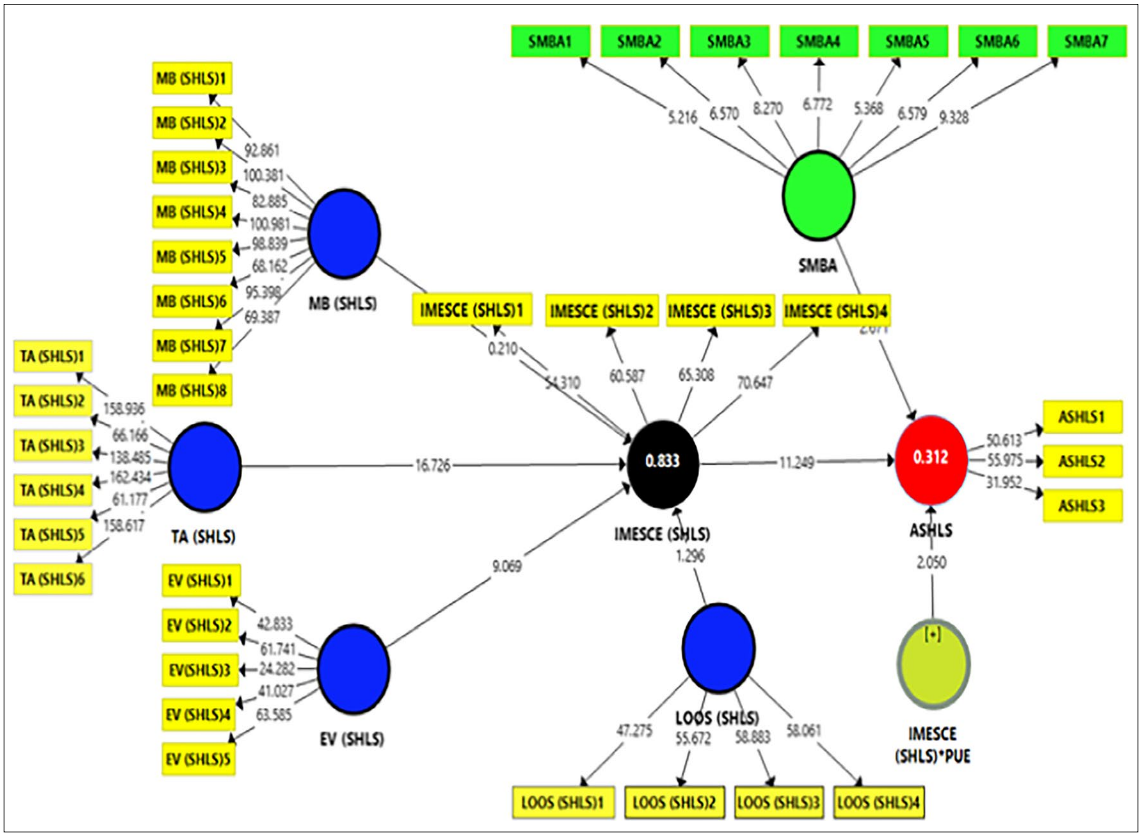


Fig. 3 Structural model assessment

Table 9 Interpretations and gratification of SHLS users and holders

Explanation	Statuses (%)	Reaction (%)	Rate
Ecological compensations	12.7	8.2	14.8
Health benefits	8.6	4.5	6.3
Availability of technicians	12.5	9.6	7.5
Use in lighting and food	5.5	10.4	7.00
Easy process of SHLS	12.6	9.4	8.5
Facilitate in cooking	8.4	8.6	7.8
Reduce workload from the grid	6.8	9.3	9.0
Economic paybacks	12.7	11.5	11.9
Advancements in modern appliances	3.7	6.3	6.2
Society improvement	5.7	8.5	6.5
Advance nutrients taste using SHLS	07.8	7.2	6.8
Others	3.0	6.5	7.7

resources in the procedural service areas to promote the growth of societal schemes in general (Breitenmoser et al. 2019). Sixty-three percent of respondents stated that user satisfaction with a Pakistani SHLS is required to adopt solar technology. About 27% of respondents indicated that lower costs and a specific policy are necessary for SHLS, while 18% acknowledged that user satisfaction and plant quality are also essential. Additionally, 50% of SHLS users reported that their conveniences are operative and usable.

Stimulating factors and significant barriers of SHLS

Multiple obstacles impede the partial adaptation of SHLS. Monitored by repeated operative issues at 16% and inadequate solar light quality at 6.5%, the most significant percentage of respondents, 16.5%, quoted a lack of professionals and entirely skilled experts. Solar facilities face various operational challenges, such as rusting brace apparatuses, rooftop and wall furious, and light waves (Ali et al. 2022a). The lowest sunlight waves have been reported during summer sessions, which pose a significant challenge to cooking food adequately (López-vargas et al. 2021). Increasing solar energy performance for end-users' benefit necessitates the correct instigation mechanism in solar facilities. The SHLS operation has been hampered by recurring technical issues, as 21% of the owners have complained. The management of SHLS required 17% of the world, 7.5% of solar lights were

Table 10 Barriers and challenging factors of SHLS

Adaptable	Explanation	Circumstances (%)	Response (%)	Frequency
Residents of SHLS are partially satisfied due to unambiguous causes	Prepared food has not satisfying taste	8	9	12.8
	Through extra workload	5	6.3	8.8
	Technicians unavailability	10	12.8	15.6
	Insufficient electricity lighting and preparing food	8	10	11
	Others	5	6.3	8.9
SHLS accepting barriers	Issues in the availability of technicians	5.6	5.4	8.4
	Additional workload	7.5	6.8	11.6
	Delay in solving technical complications	11.4	10.9	17.7
	Inadequate energy for lighting and food	8.3	9.8	12.7
	Others	9.7	6.7	14.8
SHLS's failure in operation	Normal misadventure	12	9.5	15.7
	Unfortunate and unbalanced operations of SHLS	22	15.2	43.4
	SHLS's skilled operator concerns	16	10.5	21.5
	Enabling disputes due to local check and balance	11	6.4	12.8
	Spare-parts availability problems	13	7.8	21.6
	dissatisfactory repairs	14	10.5	24.5
	Day-by-day increasing workload growing	10	13.7	15.4
	Prehistoric techniques and old-fashioned design	11	15.3	16.5
	Others	16	17.5	32.5

misplaced, and consumers of SHLS received no procedural support. Because of these influences, SHLS users experience failure and disenchantment, and the project's policy framework is held responsible for the experts' low acceptance. Deprived of a circumstantial system and mechanical support, the viability of an SHLS is significantly diminished (Pandyaswargo et al. 2019). Table 10 summarizes the obstacles and difficulties SHLS users face in Pakistan.

Discussions and implications

This study has equally hypothetical and experiential repercussions. The present notable legendary effort underwrites solar technology and socioeconomic works. The current study examines the inspiration of four influences, including the MB (SHLS), TA (SHLS), EV (SHLS), and LOOS (SHLS) as independent variables, IMESCE (SHLS) as a mediator, SMBA as moderator, and ASHLS as the dependent variable, on the acceptance of SHLS by Pakistani residents and the sustainable development of solar expertise. This study provided government sector executives, private sector policymakers, and private citizens with recommendations for reassuring residents to accept SHLS and grow solar expertise. The present research highlights the serious need for representatives, economists, and vitality segment officials to remove important obstacles and deliver monetary assistance to residents who adopt SHLS. Through superior planning, the significant components and obstacles of an SHLS can be mitigated, thereby contributing to the understanding of an SHLS. Consequently, implementing SHLS can alleviate the energy crisis and expand residents' economic circumstances.

Notwithstanding, administration support can increase SHLS embracing in pastoral zones and financier enthusiasm among original financiers. The results indicate that preservation and financial and policy barriers essential talked to entice speculation in SHLS. A substantial relationship exists between social media-based awareness and transparent policy, the implementation of SHLS, and the desirability of new investors due to cost savings and investor satisfaction with the mechanism. Carefully removing financial and policy obstacles encourages residents to adopt SHLS and enhances rural living conditions. Previous research supported similar findings (Barman et al. 2017). This study also determines that social media-based awareness is not a perfect moderator of the relationship between SHLS maintenance blockades and solar home lighting system adoption. Rendering to the study, the acceptance perspective of solar expertise in pastoral Pakistan is influenced by social media-based awareness of SHLS. The present results correspond to the discoveries of this study (Charles et al. 2018). Prior research indicates that social media-based awareness of solar home lighting systems influences installation parameters and adoption. This study also demonstrated that social media awareness of SHLS is a significant moderator between the availability of technicians for solar home lighting systems and the adoption of such systems. Dependable on a preceding study's findings (Newcombe and Ko 2017), the findings indicate that solar technology with social media-based awareness inspirations administration financial strategies and encourages pastoral residents to adopt SHLS and except currency (Narayan et al. 2018).

Conferring to the current research, the elimination of maintenance barriers and the obtainability of experts validate the intention to accept SHLS and provide societal and monetary paybacks to pastoral residents. Residents and new financiers are attracted to solar conveniences by the favorable monetary policy, reasonable cost, and repair support. Additionally, the study demonstrates an association between the economic viability of solar home lighting systems, the appeal of residents' users, and the socio-economic value of SHLS. User satisfaction and quality panels are innovative ways to entice residents and new investors to adopt SHLS, mitigating the global energy crisis and boosting the domestic economy. The study analysis demonstrates that customer satisfaction and solar panel quality can play a significant role in luring residents and new financiers to participate in SHLS in Pakistan and reap monetary and societal paybacks. The results of the research deliver representatives, professionals, official figures, controllers, power ministry, and the progressive organization of the energy board with strategies for accepting these influences for resident gratification. The responsible official establishments must contemplate MB (SHLS), TA (SHLS), EV (SHLS), and LOOS (SHLS) to save residents period, reduce prices and vitality disasters, and enhance the existing circumstances of pastoral residents who pay the reasonable cost of SHLS.

Based on the interviewees' explanations, this research also assesses the monetary paybacks of SHLS. Fifty-one percent of respondents agree that they have reduced fuel costs, while 39% disagree. In addition, 34% of respondents reported that installing an SHLS improved their household's financial situation. Fifty-six percent of respondents had no modification to their monetary condition. Consequently, this variation results from the figure of household participants and their associated expenses. In rural Pakistan, combined couples save less, whereas nuclear-powered relations are maintained and supported more through equal contributions. Fifty-three percent of families could not grip their currency due to the factors above. The current study's findings parallel those of earlier studies (Adetona and Ogunyemi 2020). Moreover, the consequences of this study indicate that the obtainability of an expert and the careful removal of repair barriers for SHLS assessing the acceptance of solar home lighting systems have a strong and positive association with the sustainable development of solar home lighting system adoption. The present study confirms the findings of a previous study, emphasizing the significance of technicians for SHLS residents adopting solar technology (Roussel et al. 2021). The present research indicates that the availability of expertise for SHLS's apparatuses encourages the acceptance of SHLS and benefits SHLS administration by removing connection obstacles. Moreover, the study's findings suggest that the maintenance barriers of solar home lighting systems positively affect the residents' adoption and motivation of SHLS. The present analysis demonstrates that government support for SHLS barrier maintenance has significant social and economic effects. These results confirm the findings of an earlier study (Opiyo 2019). This study indicates that government support for the process and repairs of solar facilities upsurges the desire to adopt SHLS and the demand for this technology among new residents.

As a result of the establishment of a biogas plant, consumer expenditures have decreased significantly. Cost decrease is the utmost critical adaptive factor for partially satisfied users at a given time. Thirty-six percent of responders noticed a substantial decline in fire incidents. Thirteen percent of respondents decided to decrease their consistent expenses on suitability. In comparison, 16% demanded disease-free, which correlated with a lack of dark dirt in the kitchen and at home. However, the primary advantages of SHLS are cleanliness and health. Forty-six percent of those questioned did not respond. Our research findings provide Pakistanis in rural areas and government employees with vital insights. The study reveals that SHLS is ideally matched for Punjab, Pakistan pastoral zones, dipping costs and fostering economic development and success. Government agencies should initiate the simultaneous deployment of SHLS with motivation and thorough information on adopting procedures to support rural people and their prosperity. In Pakistan, the implementation of SHLS appears to have optimistic and substantial associations with technician obtainability and owner gratification with panel excellence. Biogas plant owners are expected to complete SHLS maintenance requirements to reduce the costs associated with solar panel output. The research also revealed that SHLS are more beneficial when specialists and the necessary equipment are available. Assume that one family member of SHLS owners is skilled in handling maintenance issues. In such a scenario, most issues may be determined, and day-to-day expenditures may decrease. As a substitute for Punjab, the report optional expanding solar conveniences to other Pakistani provinces with administration support.

Conclusions and limitations

Solar energy is regarded globally as a potential basis for energy production. Lack of operational and technological knowledge is the most significant barrier to implementing modern SHLS in Pakistan and other stumpy nation-states. While Pakistan's administration is endeavoring to make this expertise more acceptable by subsidizing SHLS for rural residents, the rate of acceptance in rural and village communities is meager. This study's primary objective is to investigate the important difficulties and repair hindrances. Pakistani residents face when adopting SHLS. This study aims to analyze the essential characteristics of SHLS in Pakistan for the continued development of solar technology. This study aims to attract local SHLS investors to sustain solar energy by describing Pakistan's solar energy potential. Conferring to the choice philosophy of vitality, the current study region's community preferred to utilize solar in traditional farming methods over modern methods. The primary difficulty with SHLS, in contrast, was their maintenance barriers. Configuration-based encouragements, societal funding paybacks, examples of existing SHLS owners, and energy conservation primarily drive solar panel adoption. Although an increase in workload, insufficient energy for gastronomic and lights, complex SHLS procedures, methodological complications, and a lack of available experts are the furthermost mutual reasons.

In inference, the present study demonstrates that all autonomous factors are significant and positively related to pastoral Pakistan's acceptance of solar technology, mitigation of the energy disaster, and achieving cost-redeemable goals. Before implementing SHLS in pastoral zones of Pakistan, the present research determined that eradicating designated barriers is preferable and more pertinent for maintainable green vitality production, monetary organization, cost-efficiency, return on investment, and computing immovable mechanisms. This study's findings will also indicate to the government that it must take immediate action to disseminate evidence around accepting solar expertise and to launch its future expansion creativities. The R^2 value for EV (SHLS) in Table 8 is 0.46, representing that the current conceptual model has substantial descriptive energy to encourage rural Pakistani residents to use SHLS. The value of Q^2 is 0.248, representing that the theoretical background has substantial and progressive analytical significance and recommends that the specified blockades be detached to upsurge the probability of rural Pakistan accepting SHLS. The designated variables rapid their expressive association to TA (SHLS) in Fig. 1 of the model; the standards of the t figure are outcome focused on and more serious than (1.64), and TA (SHLS) has an optimistic and statistically important effect on attracting rural Pakistani residents to adopt SHLS. The significance of the moderated adjustable exhibits optimistic signals in the structural assessment model, indicating a significant association. Furthermore, the present study established that selected factors and their moderation in this theoretical prototypical significantly and positively affected the structural evaluation model for deploying SHLS in pastoral Pakistan.

The purchasers did not facilitate the after-sale facilities obtainable by solar panel organizations or organizations. The following recommendations are made to the administration of Pakistan regarding emerging and encouraging solar expertise in pastoral Pakistan. To promote SHLS, the administration should adopt a financial policy for RE project maintenance obstacles, technical support, and media complaints about maintenance. In rural Pakistan, solar expertise has great prospective to alleviate domestic vitality absences. To ensure the supportable expansion, repairs, and social media-based awareness of SHLS in rural areas, the government of Pakistan should implement some training measures. Other variables that influence the adoption of SHLS, such as poverty, SHLS owner literacy, area-specific sun waves, the required domain, and other societal and monetary influences, have been completely overlooked. Accordingly, attentive scholars must identify the remaining aspects of Shole's adoption while examining the findings of this study. We have decided to install solar panels in the rural districts of Pakistan, a developing nation. Thus, the current study's findings differ from developed and developing nations. In the future, the authors essentially explore the enticements for residents of industrialized nations to embrace solar energy facilities.

Appendix

Table 11 Part B: adoption of sustainable SHLS upgrades measures

Variables	Items	Cross-examinations	%
Technician's availability for solar home lighting systems	MB (SHLS)1	Technician availability is a factor favoring the adoption of solar home lighting systems	13.6
	MB (SHLS)2	The technician's accessibility can inspire confidence in solar home lighting system owners	16.2
	MB (SHLS)3	Because trained technicians are readily available, operators of solar home lighting systems can save time by employing one	14.5
	MB (SHLS)4	Solar home lighting systems' skilled technicians can contribute more to economic growth	12.3
	MB (SHLS)5	The availability of technicians may reduce the apprehension associated with solar home lighting systems	17.4
	MB (SHLS)6	Solar home lighting systems' capacity for maintenance can increase their sales potential	8.3
	MB (SHLS)7	The maintenance assurance of solar home lighting systems can cause the buyer to disregard the price	12.2
	MB (SHLS)8	The frequent inspections of solar home lighting systems by technicians are an attractive feature for solar panel owners	5.5
Maintenance barriers of solar home lighting systems	TA (SHLS)1	Government support for operations and maintenance can increase the adaptability of solar home lighting systems	27.5
	TA (SHLS)2	Villagers can confidently adopt solar home lighting systems with government support for operations and maintenance	24.8
	TA (SHLS)3	Government support for installing and maintaining solar home lighting systems can increase sales volume	19.5
	TA (SHLS)4	Government-funded operational and maintenance costs for solar home lighting systems can encourage farmers to adopt them	15.8
	TA (SHLS)5	Encouraging rural areas to adopt solar home lighting systems is necessary by providing them with an incentive and operational support	12.4
Economic viability of solar home lighting systems	EV (SHLS)1	The government must develop a low-cost, open strategy to encourage solar home lighting systems	27.1
	EV (SHLS)2	A transparent and low-cost solar home lighting policy can reduce the grid-connected energy load caused by adopting solar home lighting systems	22.3
	EV (SHLS)3	Over 60% of the population resides in rural areas, and we must encourage them to embrace solar home lighting systems	17.3
	EV (SHLS)4	A clear and inexpensive strategy for solar home lighting systems entices off-grid communities and residents	16.2
	EV (SHLS)5	If a clear policy and low-cost solar home lighting systems are implemented, renewable energy can significantly eliminate energy problems	17.1

Table 11 (continued)

Variables	Items	Cross-examinations	%
Level of owner's satisfaction with solar home lighting quality	LOOS (SHLS)1	User satisfaction and product quality are essential for attracting new consumers to solar home lighting systems	25.6
	LOOS (SHLS)2	The quality of solar panels enhances the satisfaction with current solar home lighting systems	23.6
	LOOS (SHLS)3	It is possible to attract new consumers with the quality of solar panels by analyzing the performance of existing solar home lighting systems	18.7
	LOOS (SHLS)4	Existing solar home lighting system customers' satisfaction is crucial for attracting new users and investors	16.5
	LOOS (SHLS)5	The quality of solar home lighting systems and user satisfaction can significantly resolve Pakistan's energy crisis	15.6
Social media-based awareness	SMBA1	Awareness of solar panel technology through social media is crucial	31.4
	SMBA2	Rural farmers must be made aware of the benefits of biogas plants	17.3
	SMBA3	Government agencies should provide villagers with information and education on renewable energy	14.8
	SMBA4	The solar panel's intelligence enables cost-effective energy production	10.6
	SMBA5	A more profound comprehension of solar home lighting systems can increase consumer satisfaction	7.9
	SMBA6	There is a lack of understanding and information concerning the operation of solar facilities, their advantages, and the amount of energy they produce	11.5
	SMBA7	The rural investor and the ordinary farmer are hesitant to adopt solar technology	6.5
Intention to moderate energy-cost and produce sustainable clean energy with solar home lighting systems	IMESCE (SHLS)1	The government can approve the solar panel dealer and information points	29.2
	IMESCE (SHLS)2	Solar panels are ideal for residents who wish to reduce energy costs and scarcity	26.2
	IMESCE (SHLS)3	By utilizing solar technology, residents can perform their duties conveniently and cost-effectively	24.3
	IMESCE (SHLS)4	The quality of solar panels enhances the satisfaction with current solar home lighting systems	20.3
Adoption of solar home lighting systems	ASHLS1	The government can approve the dealer and information service provider for solar home lighting systems	29.8
	ASHLS2	Rural investors and ordinary citizens are hesitant to adopt solar panel technology	32.5
	ASHLS3	Residents of rural areas must be aware of the advantages of solar home lighting systems	34.5

Author contribution Shahid Ali: conceptualization, writing—original draft. Qingyou Yan: analysis, data handling. Muhammad Irfan: variable construction, methodology, supervision, funding acquisition. Muhammad Sajjad Hussain: review and editing. Muhammad Arshad: review and editing. Everyone from the authors has studied and approved the document's final version.

Data availability The supporting statistics for the findings of this study are available upon reasonable request to the first author.

Declarations

Ethical approval This investigation followed the principles outlined in the Helsinki Declaration. The North China Electric Power University Authorized Valuation Board has established China (protocol 1211–12 on 03 November 2022).

Consent to participate All participants gave informed consent to participate in this study.

Consent for publication All participants consented when adequately informed about the study.

Competing interests The authors declare no competing interests.

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