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An intervention framework for the adoption of solar home system technology in rural Vhembe district, South Africa

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Abstract

Background Solar photovoltaic technology is one of the promising renewable energy solutions of the twenty-first century. It successfully provides electricity to industries, homes and even the transport sector. The decreasing prices of solar modules from 2010 have made Solar Home Systems Technology (SHST) increasingly attractive compared to other renewable energy technologies. Paradoxically, in rural communities of South Africa the usage of SHS remains low. Households continue to rely on unclean energy sources such as firewood for cooking and water heating. Previous efforts to electrify rural communities with SHS have failed considerably. Thus, a comprehensive study was conducted in the Vhembe District, encompassing three villages, to explore this issue and develop a contextualised solution using a behavioural change model. A 35-item questionnaire was randomly administered to 310 households to understand the factors that contribute to the low adoption rate of SHS technology. The data gathered were analysed using IBM SPSS Statistics and Amos version 28. Confirmatory factor analysis and hypothesis testing were employed as the principal statistical methods.

Results A 12-item model with five distinct factors consolidated into a single measurement model was revealed. All standardised factor loadings exceeded 0.7. Composite reliability values (CR) were above 0.8 and higher than MaxR(H) values, indicating the model's reliability. Among the five factors influencing SHS adoption (perceived behavioural control, attitude, intention, trust, and subjective norms), only trust and attitude significantly impacted the intention to adopt SHS in the district ($P < 0.05$). Based on these findings, the conceptualised structural model reflected SHS adoption as determined by the integration of the technology's social, technical and policy factors. Because of this, this should be regarded as a true reflection of the practical and behavioural intentions of local communities. Moreover, in this paper the barriers hindering SHS adoption are explained, emphasising the significance of attitude and trust. Highlights of policy imperatives are included together with a proposal for a contextual framework, and the way of promoting sustainable solutions. Emphasis is placed on the importance of scaling up renewable energy access.

Conclusions This research provides a compelling academic exploration of the barriers to the adoption of SHS, the influential role of attitudes and trust, policy considerations, a contextual framework, and the need for promoting sustainable solutions and expanding access to renewable energy. The South African government should lead a change in how solar PV is deployed, considering its social impact, associated technical skills and policy support.

Keywords Intention, Solar home system (SHS), Solar home system uptake, Solar home system adoption interventions, Planned behaviour

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Background

Sub-Saharan Africa exhibits a relatively low electrification rate (45%) compared to the other parts of the world, with an estimated 600 million people lacking access to electricity [1]. Even those, connected to the grid, experience the detrimental effects of frequent power outages and unreliable connections [2, 3]. To address these challenges, decentralised systems for example Solar Home Systems (SHS) are cost-effective solutions that can be implemented and expanded to enhance access to clean and affordable energy sources [4, 5]. However, despite their potential, the global adoption rate SHS remains limited [6]. In South Africa, approximately 15% of the population does not have access to electricity [7]. Considering that the decision to adopt SHS technology hinges upon affordability and the behaviour and attitudes of individual households, which may accept or reject the technology, it is crucial to understand their beliefs which shape their intentions. Therefore, a behavioural approach is essential because it uncovers the determinants of SHS adoption in the Vhembe District of South Africa.

Implementation of the Integrated National Electrification Project (INEP) in 1999 marked South Africa's initial endeavours to incorporate solar photovoltaic (PV) technologies into isolated and widely dispersed households (INEP) [8]. Over its 5-year duration, the program aimed to install solar home systems (SHS) in approximately 300,000 households to provide electricity [9]. Initial progress was notable, with approximately 40,000 SHS installed by 2000 [7]. However, the subsequent outcomes were disappointing, with only 150,000 SHS being implemented by 2017, and a mere 60,000 are currently in use [7, 10]. The program's failure has primarily been attributed to its rigid and static design, inadequate planning and inadequate government support [8]. The government bears exclusive responsibility for this outcome, given that there is no evidence of the government and its partners conducting a comprehensive analysis of requirements to identify the contextual and circumstantial factors that might influence the program's success [8]. Household opinions, attitudes and intentions were disregarded, with the government promoting the Energy for All Campaign, which prioritised grid electricity over rooftop SHS [7]. Consequently, this reinforces the longstanding notion that solar technology is employed for political purposes, to pacify rural communities and create an illusion of electricity connections that fail to meet their immediate power needs. Therefore, in this paper the deliberate preference for rooftop SHS is examined and the attitudes, perceived behavioural control, trust and normative control inherent in rural South African societies are explored.

Theoretical framework

The theory of planned behaviour (TPB) guided this study, which posits that attitude, subjective norm and perceived behavioural control (PBC) determine behavioural intention [11]. Accordingly, attitudes towards solar systems, subjective norms and PBC are antecedents for households to adopt a SHS. Notably, the TPB framework allows for inclusion of additional determinants beyond those specified if they enhance the model's predictive power. In this study, attitude represents an individual's inclination to adopt a SHS, reflecting his/her intention to embrace rooftop solar panels systems [12, 13].

Subjective norm is the second component of the theory, which encompasses individuals' perception of social pressures that significant others exerted, which compels them to engage in a specific behaviour [13, 14]. The final component, PBC, refers to individuals' perceptions of factors that may facilitate or hinder their engagement in a particular behaviour [15]. In the context of this study, PBC is the perceived ease or difficulty of adopting a SHS [13]. Notably, trust was incorporated as an external variable due to its influence on the intention to adopt a SHS. It has been considered in related studies using the TPB framework and is treated as an external predictor that positively correlates with behavioural intention. In the context of this study, trust represents an individual's confidence in the reliability and effectiveness of the SHS. It is the foundation upon which households believe that adopting a SHS meets their energy needs securely and efficiently. Even though this variable is external to the traditional TPB components, it has been critical in related research using the TPB framework [16]. As with other constructs, trust significantly shapes behavioural intention, especially with respect to adoption of new systems or technologies.

Research objectives and hypotheses

In this paper, the aim is to accomplish two objectives, namely to: (a) identify the factors that shape adoption of SHS in the District, and (b) propose an intervention framework for adopting SHS technology. Based on these objectives, the following hypotheses were formulated:

Hypothesis 1 (H_1): A positive association exists between attitude towards solar energy and the intention to adopt a SHS.
Hypothesis 2 (H_2): Subjective norm positively influences the intention to adopt a SHS.
Hypothesis 3 (H_3): Perceived behavioural control positively influences the intention to adopt a SHS.
Hypothesis 4 (H_4): Trust in solar energy positively influences the intention to adopt a SHS.

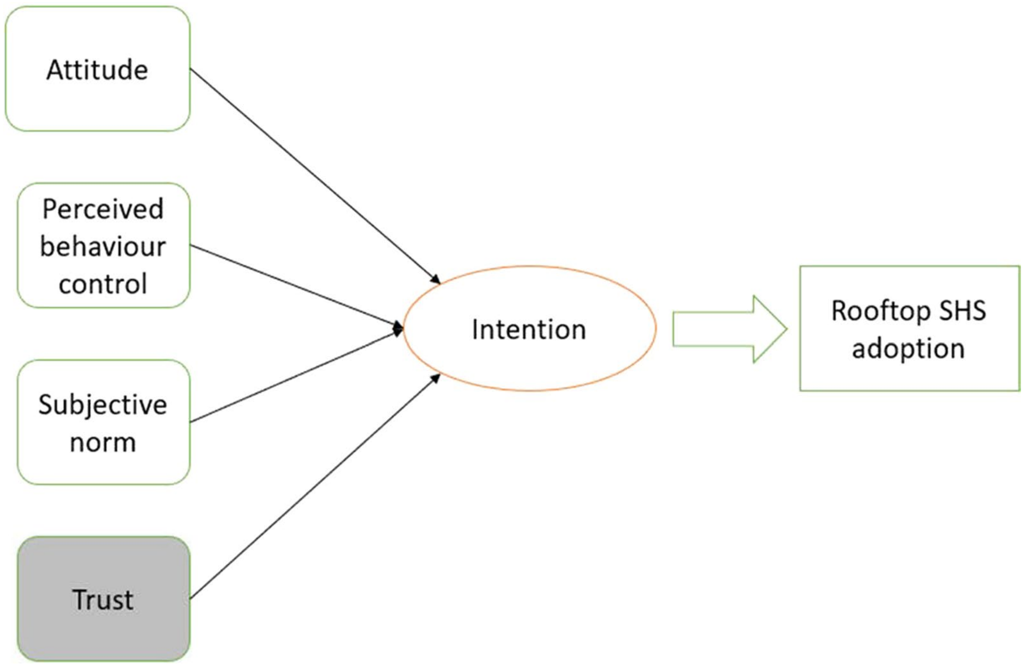

Fig. 1 The extended theory of planned behaviour

In line with the research objectives, these hypotheses were examined to provide insights into the factors influencing SHS adoption as well as supporting the development of an effective intervention framework. All the hypothesised relationships are shown in Fig. 1.

Methods

The survey was conducted in Duvhuledza, Mbahe, and Tshamuntilikwa villages of Vhembe District in Limpopo Province of South Africa. All the three villages are rural communities with substantial solar irradiation, making them prime candidates for solar energy. Despite this potential, they primarily rely on traditional energy sources mainly due to infrastructural and economic barriers. High poverty and unemployment rates characterised the three villages. Presumably, this made residents hesitant to adopt new technologies such as off-grid SHS due to upfront costs associated with them [17]. However, their consistent solar exposure makes a strong case for SHS as a sustainable energy solution. To enhance the comprehensive nature of the study, insights from relevant literature sources such as [18–20] were incorporated into the questionnaire design. In this respect, the existing knowledge was summed up in a Likert-type scale to create a measure of construct. Consistency and comparability criteria between items were satisfied. The TACT (Target, Action Context and Time) technique of Ajzen described in [21] was employed to ensure clarity and precision in conceptualising key constructs within the questionnaire. Specifically, the term "solar home system" was used to define the target technology, with "purchase" referring to the actual adoption process. "For me or my home" established the context and "in the next few years" denoted the specified time frame.

Survey design

The survey design adhered to the structure that Ajzen outlined in [21], encompassing households' intentions, and behavioural, normative and control beliefs concerning the adoption of SHS. To capture respondents' perspectives, unimodal scales ranging from 1 to 7 were employed to gauge semantic differences. Likert-type scales, ranging from 1 (Strongly Disagree) to 7 (Strongly Agree), were employed to gather survey responses. In addition to the constructs related to SHS adoption, the questionnaire included demographic information and details regarding households' current energy sources and usage. The final version of the questionnaire comprised 35 items, measuring five factors, viz: intention, attitude, subjective norms, perceived behavioural control and trust.

Data collection

Data were collected from July to September 2022. A total of 310 participants were randomly selected from Duvhuledza (90), Mbahe (100) and Tshamutilikwa (120). This was carried out via face-to-face interviews involving randomly selected households. Before administering the questionnaire, the interviewers explained and described the SHS technology. The participants were allowed to ask questions on aspects they did not understand. This was necessary because it made it possible for even those without a priori technical background knowledge to make informed responses during the questionnaire survey. In South Africa, households possess the individual right to transition to solar photovoltaics. Homes were randomly chosen for inclusion in the study. Before soliciting information, each household approached for participation in the study was provided with a comprehensive explanation of the study's purpose, participation rights and the informed consent process.

Data analysis

Initially, exploratory factor analysis (EFA) was conducted using the IBM SPSS Statistics 28 software to assess the hypothesised constructs' factor structure, reliability and validity. Subsequently, a path analysis was performed using IBM Amos 28 to test the conceptual model and examine the study hypotheses, following the [22] guidelines. The data were analysed using IBM SPSS Statistics and IBM Amos version 28. Following the decision rules developed by Coltman et al. [23], the proposed model adhered to a reflective framework. structural equation modelling (SEM) was used to examine correlations among variables while considering the specified directions of influence [24]. The proposed model was evaluated based on several criteria for its fit with the data. It was deemed to be a good fit if it met the following minimum thresholds: $p < 0.001$, Chi-square/degree of freedom $(X^2/df) < 3$, root mean square error of approximation (RMSEA) < 0.08, standardised root mean residual (SRMR) < 0.05, Tucker Lewis Index (TLI) > 0.90 and comparative fit index (CFI) > 0.90, as per Hair's recommendation [25].

Results

Demographic characteristics of the respondents

More than half of the study participants (56.5%) were identified as females, and 53.3% were classified as adults. Youth and the elderly accounted for 25.5% and 22.3% of the sample, respectively. Approximately 44% of the local households reported a SHS usage period ranging from one to five years. More than 33% of the families had never used SHS. There were more than 15% of households that had been using SHS for six to ten years. Less than 5% had been employing it for more than ten years. Lastly, over 35% of the households had never used a SHS. Regarding the highest education attainment, more than half of the sampled households possessed secondary education qualifications. About 18.4% of them had completed primary education. It was observed that 10% of the household heads had not received any formal education. Less than 10% had attained degree qualifications.

A considerably high proportion (44.8%) of the households relied on government grants compared to 17.1% which depended on income from business investments. Approximately 15% of the households depended on salaried employees and pensioners (10%). Worth noting was that 13.9% of the households revealed that they did not have any source of income. The majority (53.5%) of the households received less than R1000 (US$1 = ZAR18,82) per month. About a third of the households reported monthly earnings ranging from R1000 to R5000. A modest proportion (12.3%) of households earned between R5000 and R10 000 monthly. Only 3.2% reported that they received incomes exceeding R10 000 each month. Respectively, 33.9%, 17.4% and 16.5% of the respondents reported that they belonged to households consisting of four, five and more than six members. As shown in Table 1, 18.7% and 11.9% of the households had two and three family members, respectively. Lastly, a negligible proportion (1.3%) of the respondents reported that they stayed alone.

Model measurement (reliability and validity)

The hypothesised model (Fig. 1) measured for both reliability and validity against the observed data. Firstly, the constructs' reliability was assessed using Cronbach's alpha values (α) and composite reliability values (CRV). A minimum factor loading of 0.70 was considered to establish reliability based on the guidelines described in [25, 26]. It is shown in Table 3 that all the constructs successfully passed the reliability test. The convergent validity of each construct was evaluated through confirmatory factor analysis (CFA). Anderson and Gerbing contend that all factors should have factor loadings exceeding 0.60 to establish convergent validity [27]. While Chiu and Wang [28] suggest that a factor loading of 0.50 is sufficient, the threshold that Anderson and Gerbing [27] set was adopted because of its widespread use. Taking into consideration the composite values obtained, all the constructs exceeded the minimum validity thresholds. Moreover, the discriminant validity of the constructs was assessed by ensuring that the square root of the average variance extracted for each one of them was higher than the highest squared correlation with any other variables (Table 2). To examine the common method bias, Herman's one-factor test was conducted. This involved running a principal component analysis while fixing the total number of factors to extract at 1. The total variance extracted from the analysis was 34.550%. The data passed the common method bias test because the total

Table 1 Demographic characteristics of the participants

Variable		Frequency ($n=310$)	Percentage (%)
Sex	Female	175	56.5
	Male	135	43.5
Age	18–35 years (youth)	79	25.5
	36–59 years (adults)	162	52.2
	60 + years (elderly)	69	22.3
Number of years of solar usage	0 years	111	35.8
	1–5 years	137	44.2
	6–10 years	48	15.5
	11–15 years	8	2.6
	16–20 years	2	0.6
	0ver 20 years	4	1.3
Level of education	No education	30	9.7
	Primary	57	18.4
	Secondary	165	53.2
	Certificate	30	9.7
	Diploma	16	5.2
	Bachelor's degree	10	3.2
	Postgraduate degree	2	0.6
Sources of income	Wage or salary	45	14.5
	Investment (business) income	53	17.1
	Government grant	139	44.8
	Pension	30	9.7
	No source of income	43	13.9
Average monthly household income	Less than R1000	166	53.5
	Between R1001-R5000	96	31.0
	Between R5001-R10 000	38	12.3
	Over R10 000	10	3.2
Number of people in a household	One	5	1.6
	Two	58	18.7
	Three	37	11.9
	Four	105	33.9
	Five	54	17.4
	Six and above	51	16.5

Table 2 Discriminant validity

	CR	AVE	MSV	MaxR(H)	1	2	3	4	5
1	0.906	0.709	0.234	0.943	0.842				
2	0.838	0.721	0.270	0.838	0.253***	0.849			
3	0.903	0.823	0.328	0.917	0.241***	0.520***	0.907		
4	0.893	0.806	0.234	0.986	0.484***	0.362***	0.301***	0.898	
5	0.926	0.863	0.328	0.927	0.161**	0.501***	0.573***	0.261***	0.929

**$p \le 0.01$ (highly significant), ***$p \le 0.001$ (very highly significant)

variance extracted was below the recommended threshold of ≤ 50%.

Various model parameters were measured to assess the robust convergent validity of the constructs. This included standardised factor loading coefficients, average

Table 3 Confirmatory factor analysis

Construct/items	Standardised loadings
1. Perceived behavioural control (AVE = 0.709, CR = 0.906, α = 0.914)	
We have sufficient organisational and institutional support for solar adoption in this country	0.955
Existing regulations are sufficient to facilitate solar home system adoption	0.713
The current institutional framework facilitates solar home system adoption	0.875
Current government subsidies are promoting solar home system adoption	0.807
2. Attitude (AVE = 0.721, CR = 0.838, α = 0.870 =)	
In my view, solar panels used in solar home systems are durable	0.844
In my view, lithium batteries used in the solar system are durable	0.854
3. Trust (AVE = 0.823, CR = 0.903, α = 0.912)	
I trust the power generated by solar panels	0.942
I trust household electrification with solar photovoltaics	0.871
4. Subjective norms (AVE = 0.806, CR = 0.893, α = 0.886)	
Our government is interested in electrifying rural communities with solar home systems	0.915
There is a possibility of the government recommending rural household electrification with solar home systems	0.881
5. Intention (AVE = 0.863, CR = 0.926, α = 0.700)	
I will indeed buy a solar home system for my home	0.922
I want to install a solar home system at my home	0.936

variance extracted (AVE), and composite reliability (CR). The AVE values were compared with the correlations with other variables to ensure that each construct had higher AVE values. According to the approach described in [26], the AVE should exceed 0.5, while the CR (Joreskog p-value) is expected to be > 0.7 to establish a high level of convergent validity for the constructs. Evaluation of the AVE, CR and Cronbach's Alpha values of each construct in the conceptual model revealed that their magnitudes exceeded the minimum threshold requirements (Table 3). These findings indicate that the constructs exhibited satisfactory convergent validity. This suggested that they adequately measured the study's underlying latent variables of interest.

Table 4 Model fit statistics

Measure	Estimate	Threshold	Interpretation
X^2	120.157	–	–
d.f	44.00	–	–
X^2/d.f	2.731	Between 1 and 3	Excellent
CFI	0.970	> 0.95	Excellent
SRMR	0.033	< 0.08	Excellent
RMSEA	0.075	> 0.05	Acceptable
TLI	0.955	> 0.90	Excellent

Table 5 Structural modelling analysis and hypothesis testing

Hypothesis	Constructs and paths	Standardised coefficients	*β*-values	*p* value
H1	PBC⟶intention	− 0.035	*0.061*	*0.548*
H2	Attitude⟶intention	0.271	*0.081*	***
H3	Trust⟶intention	0.425	*0.058*	***
H4	Subjective norms⟶intention	0.053	*0.038*	*0.405*

***$p \leq 0.001$ (very highly significant)

Structural modelling (goodness of fit)

To examine the significance and strength of the hypothesised relationships between variables, SEM was conducted. The results presented in Table 4 indicate that the proposed model met these criteria, thereby suggesting a satisfactory fit to the data. In addition to this, the SEM analysis was used to estimate the standardised path coefficients and t-tests were carried out to examine the hypotheses (Table 5). This allowed for an evaluation of the strength and significance of the relationships between the variables fitted in the model.

As indicated in Table 5, the model's results indicated that attitude towards solar home systems and trust in solar energy had a statistically significant ($P < 0.05$) and positive impact on the behavioural intention to adopt a SHS in the three villages that participated in the study. Thus, Hypotheses H_1 and H_4 were rejected in this model. However, the results suggested that perceived behavioural control and subjective norms did not significantly influence the behavioural intention to adopt a SHS. Consequently, Hypotheses H_2 and H_3 were supported in this

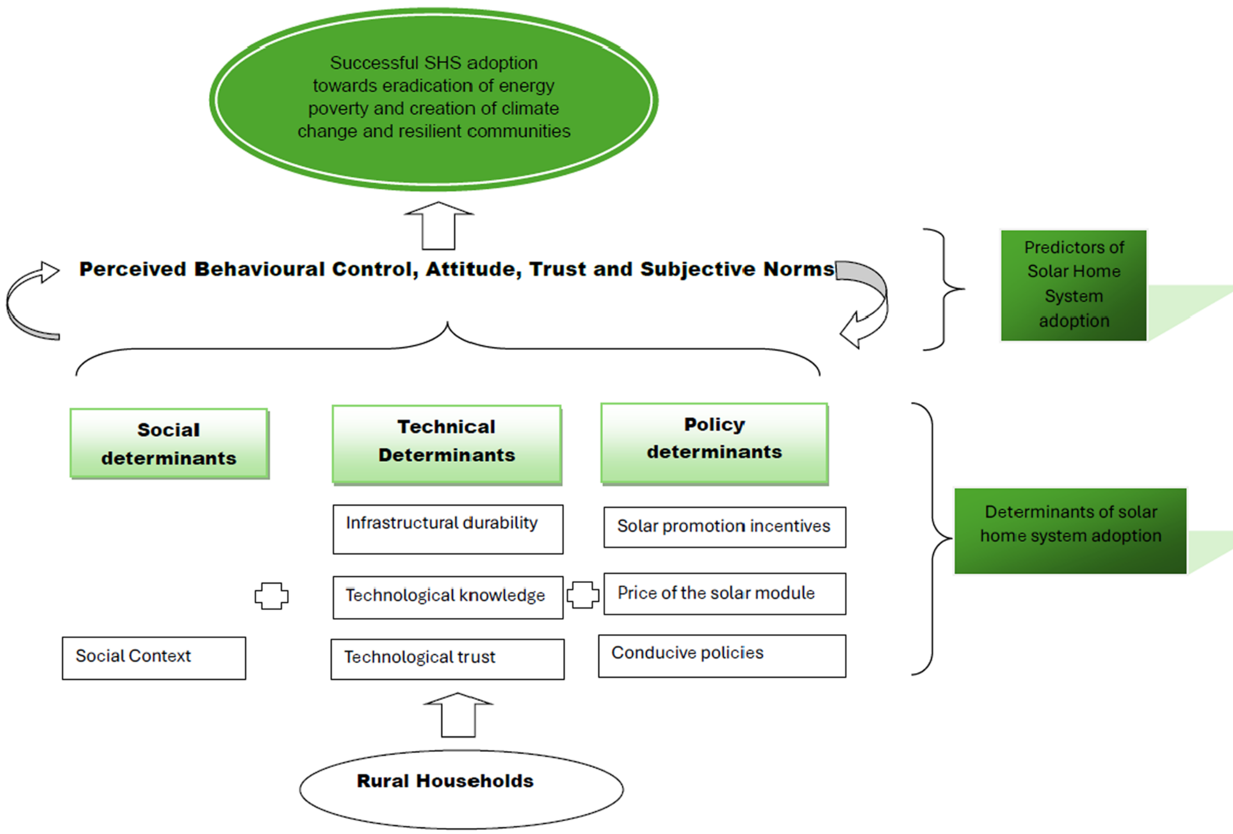

Fig. 2 Proposed SHS adoption framework in Vhembe district

study. No significant positive relationship was observed between perceived behavioural control and subjective norms on the intention to adopt a SHS. This suggested that perceived behavioural control and subjective norms did not exert a favourable influence on the behavioural intention to adopt a SHS.

Discussion

Several factors were found to influence the constructs related to the adoption of SHSs. Policy framework, price of the solar module, knowledge of the technology and solar promotion incentives influenced PBC. Perception of infrastructural durability, especially with respect to solar panels and batteries shaped attitude. Furthermore, it was revealed that level of trust in the power that solar panels generated influenced both trust in the technology and general electrification process. Another observation was that social contexts such as the perceived government interest and potential to recommend rural electrification with solar systems shaped both descriptive and injunctive norms. Thus, based on the results presented above, the key determinants of solar home system adoption in the district encompass policies, price of the solar module, knowledge of the technology, infrastructural durability, technological trust, social contexts and solar promotion incentives such as government subsidies.

Proposed solar home system adoption intervention

To address the unique challenges prevalent in rural communities of South Africa, an intervention model consisting of social, technical and policy factors as key pillars is proposed. These factors were constituted after categorising all the extracted factors (Fig. 2). It is noteworthy that all these factors were drawn from the determinants of intention, namely attitude, PBC, subjective norms and trust. This comprehensive model is meant to facilitate the successful adoption of the district's solar home systems (SHS).

The first pillar of the model emphasises the significance of understanding the social context parameters that influence human behavioural intentions. This approach recognises that comprehending the social dynamics surrounding adoption of renewable energy sources, for example SHS, is crucial. Previous studies have acknowledged the need for incorporating social context issues to enhance SHS adoption [29–31]. Factors such as peer effects within the neighbourhood, socialisation processes, peer behaviour and societal expectations significantly determine households' intentions towards adopting SHS. It is assumed that social pressures stemming from adherence to specific societal norms influence households' motivation to adopt SHS. The significance attributed to peers who embody descriptive or injunctive norms, consequently shaping households' compliance determines the strength of normative beliefs. Also, successful implementation of SHS initiatives can be facilitated via building a comprehensive understanding of the influence of social contexts on normative beliefs alongside technical and policy factors.

To ensure successful adoption of SHS, it is proposed that attention be given to the factors influencing durability of infrastructure, technical knowledge and technological trust. Studies conducted in various regions in the past have consistently highlighted the importance of addressing the technical aspects associated with SHS adoption. For instance, the studies presented in [32–34] have all emphasised the lack of technical support as a barrier to the adoption of solar technologies. Similarly, Garlet et al. note the scarcity of technicians as a hindrance to solar adoption in Brazil [35]. Evidence from studies conducted in Pakistan [36], Vietnam [34] and Sweden [37] reveals that lack of technical knowledge among rural households is a significant obstacle to SHS adoption. Successful adoption of SHS depends on the availability of durable and reliable technology and that end-users possess adequate knowledge about and trust. These observations confirm the findings of studies carried out in other geographical locations and contexts. In the latter studies, the technical viability of solar photovoltaics has been found to play a crucial role in determining its adoption. Thus, addressing technical barriers and ensuring the durability and trustworthiness of the technology are critical steps towards facilitating the widespread adoption of SHS.

In the current study, it is recommended that a comprehensive policy review be conducted to address key aspects such as promotional incentives, pricing and removal of obstacles to create an enabling environment for the adoption of SHS. Similar recommendations have been made in various countries. For instance, Do et al. identified regulatory mismatches, complex administrative procedures, entrenched subsidies for fossil fuels and policy uncertainty as significant barriers to solar photovoltaic (PV) adoption in Vietnam [34]. Palm highlighted similar challenges in Sweden [37]. In the United Kingdom, Balcombe et al. noted the lack of subsidies, regulatory and subsidy uncertainties, and inadequate organisational and institutional support as barriers to solar usage [38]. Lack of coordination and cooperation among various ministries, agencies, institutes and stakeholders were identified as factors that impeded the progress of renewable energy development and commercialisation in Pakistan [36]. Apart from this, the absence of a centralised body that would coordinate energy sector activities was said to have led to duplication of research and development efforts, posing additional challenges in Pakistan.

Successful adoption of SHS should be preceded by revisiting existing policies and ensure the provision of adequate solar promotional incentives, affordable pricing of SHS for rural households with limited income sources, and the resolution of bottlenecks and contradictions. Zubi et al. caution against the availability of technology that may be unaffordable for end-users [32]. This highlights the need for the proposed policies to be inclusive, in addition to prioritising the needs of the intended beneficiaries rather than catering solely for elite consumers. Thus, the proposed policy framework should be designed to empower and engage end-users in driving the adoption of SHS while addressing affordability concerns and ensuring equitable access to solar energy solutions.

The conceptual model developed in this study is grounded in the lived realities and experiences of rural households in the Vhembe District Municipality. It considers the local community's specific context and behavioural intentions. While developing a universal model for adopting SHS is valuable, it is crucial to recognise and account for the local variations and intricacies that influence the acceptability of the technology. The contextualised model presented here provides a framework that allows stakeholders to understand the specific determinants that shape the behavioural discourse and influence the acceptance of SHS within the local community. Through incorporating end-users' perspectives and considering their unique local realities, this model offers a nuanced approach to understanding the dynamics and factors influencing the adoption of SHS. Emphasis on the local context and including end-users' perspectives are crucial because they make the proposed model distinct, unique, and versatile. It acknowledges the importance of capturing the specific local dynamics and key determinants that shape the acceptance of SHS, contributing to a more comprehensive understanding of the technology adoption process within a given community.

Another notable strength of the proposed model is its exclusive focus on determinants associated with rural households. This distinguishes it from many contemporary models or interventions that primarily address urban contexts and rely on secondary data from international development institutions such as the World Bank. The development of the proposed model followed a participatory approach, actively involving the end-users of the technology residing in remote villages within Vhembe District. This means that rural households' practical lived experiences and contextual realities informed the nature and form of the model. Thus, it can be argued that the participatory approach facilitated the nurturing of a sense of ownership over the intervention model. This bottom-up approach distinguishes the proposed model and intervention from existing approaches that have not adequately addressed the specific nuances and challenges associated with adopting SHS in rural areas.

Although the proposed model exhibits uniqueness within the South African context, its underlying propositions align with research findings from various countries. The significance of social contexts as drivers of SHS technology adoption has been recognised in various studies [29–31]. Similarly, the identified technical determinants have been addressed in many studies, among which are [32–37, 39]. The role of policy, both as an enabler and inhibitor of technology adoption, has been widely reported in the works of [32, 36–38]. These imperatives highlight that the proposed intervention model is not an isolated intellectual product but shares similar realities in other regions worldwide.

One weakness of the intervention model is its reliance on societal beliefs, including normative, trust, control and behavioural beliefs. All these constructs are fluid and change over time. As the Community-Based Resilience Analysis (2004) reveals, conceptual models are best developed through repeated assessments that track trends, attributes and progress in behavioural change. Consequently, the proposed model would benefit from implementation and regular testing over time to enhance its reliability and accuracy. Nevertheless, the current conceptualised model provides the foundation for ongoing assessments to facilitate successful SHS adoption.

Conclusions

Various factors, including regulatory policies, solar module prices, technological knowledge, infrastructural durability, technological trust, social contexts and solar promotion incentives influence the adoption of SHS in Vhembe District. These determinants were used to develop a framework for SHS adoption, encompassing social, technical and policy imperatives associated with rural households. The proposed framework is a product of robust participatory approaches involving SHS end-users. It is designed to ensure that the intervention model reflects rural households' practical realities and behavioural intentions. While the model exhibits uniqueness within the South African context, its propositions align with findings from studies conducted in other global contexts.

It is essential to acknowledge weaknesses in the intervention model. Among these are its reliance on societal beliefs such as normative, trust, control and behavioural beliefs. These are fluid constructs and thus change over time. For this reason, the proposed model should be implemented and repeatedly tested to enhance its reliability and accuracy. Nonetheless, the current conceptualised model provides a foundation for ongoing assessments to facilitate successful SHS adoption in the district. The findings of the study present a compelling argument for recommending that policymakers and stakeholders involved in solar photovoltaic deployment among rural communities should consider the social, technical and policy determinants that shape adoption behaviour. A paradigm shift is necessary for the overall approach to solar PV deployment, with the government taking the lead in planning and implementation while being cognizant of the technology's social contexts, technical competences and policy enablers. Furthermore, further research is needed to validate the proposed model. Lastly, a comprehensive SHS adoption index should be developed and measured through longitudinal studies. This would deepen understanding of the factors influencing SHS adoption and inform future practical interventions.

Appendix 1: Questionnaire

Instructions

Kindly answer the following questions by circling the number that best describes your opinion. Please note that some questions may appear similar, but they address different issues. Read each question carefully.

Name of the village ____________________________

Section A: participants demographic information	Response
1.1 Sex	
1.2 Age	
1.3 Please indicate the number of years that you have been using solar energy	
1.4 Indicate your highest level of education	
1.5 Source of Income	
1.6 Average Household monthly income	
1.7 Number of household members	
Main household source of energy	
1.9 What do you use for the following? i. Cooking	
ii. Space heating	
iii. Air conditioning	
iv. Water heating	
v. Lighting	
vi. Refrigeration	
vii. Entertainment	
viii. Other (Specify)	

Key to responses: 1 = Extremely Good, 2 = Quite Good, 3 = Slightly Good, 4 = Neither, 5 = Slightly Bad, 6 = Quite Bad & 7 = Extremely Bad.

Section B: attitude	Response
A1: In my view, SHS is a good alternative energy for your household	
A2: In my view, solar panels are durable	
A3: In my view lithium batteries used in SHS are durable	
A4: In my view, the cost of SHS is fair	
A5: I think, I like to electrify my household with SHS	

Section C: subject norms	Response
N1: I think my friends would approve the use of SHS at our home	
N2: I think my relatives would approve the use of SHS at our home	
N3: I think I would approve the use of SHS for my relatives	
N4: I think, I would approve the use of SHS for my friends at their houses	
N5: In my view, I think the government would approve SHS adoption	
N6: In my view, I would approve any government and other stakeholders` initiatives to electrify rural communities with SHS?	

Section D: perceived behavioural control	Response
C1: I think there are enough technical experts to service the SHS	
C2: I think SHS are affordable in general	
C3: I think servicing a SHS is affordable to the local households	
C4: In my view, I think the existing regulation of SHS adoption are good	
C5: I think, the current SHS subsidies are promoting SHS adoption	
C6: In my view, am satisfied with the current organisational and institutional support of the SHS	
C7: In my view, am satisfied with the current institutional framework for the adoption of SHS	
C8: I think the initial cost of installing a solar home system is affordable	
C9: In my view, am satisfied with the government investments in SHS adoption	
C10: In my view, am satisfied with private investments in solar SHS adoption	
C11: I think SHS consumers are knowledgeable about the SHS in the village	

Section E: trust	Response
T1: I trust rural household electrification with SHS	
T2: I trust solar panels used in SHS electrification	
T3: I trust the lithium batteries used for storing electrical energy generated by a SHS	

Abbreviations

AVE	Average variance extracted
CFA	Confirmatory factor analysis
CFI	Comparative fit index
CR	Composite reliability
CRV	Composite reliability value
CV	Composite values
IEA	International Energy Agency
INEP	Integrated National Electrification Project
IRENA	International Renewable Energy Agency
MSV	Maximum shared variance
PBC	Perceived behavioural control
PV	Photovoltaics
RMSEA	Root mean square error of approximation
SEM	Structural equation modelling
SHS	Solar home systems
SRMR	Standardised root mean residual
TACT	Target, action, context and time
TLI	Tucker Lewis Index
TPB	Theory of planned behaviour

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Ranganai Chidembo conceptualised the paper, collected, analysed and wrote the draft manuscript. Joseph Francis and Simbarashe Kativhu supervised the work. In addition, Joseph Francis formatted, proofread, and language edited the manuscript.

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Declarations

Ethics approval and consent to participate
The Animal, Environment and Biosafety Research Ethics Committee at the University of Venda, Research Ethics Committee approved the study as straightforward research without ethical problems (Category 1) under ethical clearance number SARDF/21/IRD/10/1210.

Consent for publication
All the research participants voluntarily participated in this study. All their rights were expressed and explained clearly both in writing and verbally.

Competing interests
The authors declare no competing interests.

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