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Original research article

Community-led solar energy technology adoption in rural Zambia: The role of observational learning and neighbor influence

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A R T I C L E I N F O

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A B S T R A C T

Solar PV technology holds significant potential for addressing energy access issues in rural Zambia. However, adoption rates remain low despite numerous interventions. This study explores the impact of community-based interventions, leveraging local networks, individual benefits, and peer consultation, on accelerating PV adoption and willingness to pay. The primary aim is to understand how social and individual benefits influence PV adoption intention and examine the relationship between visual exposure to solar technology and adoption intention. The research seeks to inform policies and interventions that promote sustainable energy access and socio-economic development in rural Zambia and similar contexts. Over 6 months, a qualitative study was conducted involving 58 interviews, 7 focus group discussions, pictorial evidence, and observational techniques. The study engaged 120 rural subsistence farmers and 16 commercial farmers across three regions of Zambia, using five local languages. The research employed the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) that was developed for this research, which combines the Theory of Planned Behavior (TPB), the Technology Acceptance Model (TAM), and Diffusion of Innovations (DOI) theory. Findings reveal that shifting individual and community mindsets is crucial for project sustainability. Emphasizing individual benefits leads to broader community advantages as participation increases. Additionally, PV adoption and willingness to pay can be catalysed through systematic knowledge dissemination and leveraging peer and social influence. The study highlights the need for donors to deepen their understanding of poverty to make effective interventions. These insights provide a foundation for developing targeted strategies to enhance PV adoption in rural settings.

1. Introduction

The global energy landscape is witnessing a significant shift driven by renewable energy (RE) technologies, particularly solar photovoltaic (PV) and wind, which collectively account for 70 % of global power capacity expansion [1]. Rooftop PV systems are gaining widespread acceptance among populations [2]. The increasing popularity of solar communities, attributed to the falling prices of PV panels and enhanced PV efficiency, demonstrates the potential for PV panels to become a primary energy generation element in local energy contexts worldwide [3]. In emerging economies, renewable energy technologies, particularly solar PV, are recognized as essential components in sustainable energy development, offering promising solutions to address energy poverty and achieve long-term sustainable energy goals [4,5].

Energy poverty in the rural African context refers to the lack of access to modern energy services such as electricity and clean cooking facilities. This condition is characterized by the reliance on traditional biomass (e.g. wood, charcoal, dung) and kerosene for lighting and cooking, which are inefficient and harmful to health and the environment [6]. Despite global initiatives, energy poverty remains a pressing issue, with over 573 million people in Africa and 840 million globally lacking access to electricity, and over 2.7 billion lacking access to clean cooking energy, primarily in developing countries [7].

The identification of solar PV technology as the largest available renewable energy source highlights its potential to alleviate energy poverty and drive socio-economic development, particularly in regions with limited energy access [8]. While the rapid growth in global energy demand and concerns about dwindling fossil fuel reserves and climate

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change have prompted policy interventions to promote renewable energy adoption, challenges persist, especially in developing countries [9].

In Zambia, despite an average solar insolation level of 5.5 kWh/m2/day and 3000 h of sunshine per year, only 3.23 % (123.13 MW) of its installed generation capacity is solar based, predominantly utilized for basic energy services such as lighting and mobile phone (also referred to as cell phones in other parts of the world) charging [10]. Presently, 64 % to 84 % of the Zambian populace lacks access to electricity, a fundamental prerequisite for socio-economic advancement and poverty mitigation [11]. Rural electrification rates are strikingly low, with <6 % of rural dwellers having access to electricity, leaving over 94 % of rural inhabitants in darkness [12]. Zambia's energy landscape is further strained by an inadequate national grid exacerbated by reliance on hydroelectric power susceptible to climatic fluctuations. Climate-induced droughts have diminished hydroelectric output, precipitating frequent power rationing episodes lasting up to eight hours daily [10]. Consequently, the country grapples with a substantial electricity deficit of 1000 MW amidst a growing demand of 3812.07 MW [10,13,14], culminating in adverse economic ramifications such as reduced productivity, job losses, and diminished tax revenues. These energy shortages intensify developmental challenges within and across various sectors including healthcare, education, food security, and poverty alleviation [15].

In response to the existing energy challenges, the Zambian government has outlined a diversification plan of energy sources, particularly toward off-grid and renewable energy, as a cornerstone of its 8th National Development Plan (2022–2026) aimed at achieving universal, clean, abundant, and affordable energy access [16]. Notwithstanding governmental efforts, only 6 % of the rural population has gained electricity access, exposing the inadequacy of current strategies [10]. Challenges persist in expanding energy access to rural communities, worsened by limited government budgets and insufficient community engagement. Extant literature shows that, compared with diesel-powered electricity generation systems, solar photovoltaic systems are more affordable to no <36 % of the unelectrified populations in East Asia, South Asia, and sub-Saharan Africa [17]. While the cost of Solar PV has decreased in recent years, energy service provision through RE remains capital-intensive, necessitating substantial upfront investments beyond the capacity of public budgets [18]. In the context of energy applications, this means that seeing neighbors or community members successfully using solar PV can significantly increase the likelihood of others adopting similar systems. This effect is particularly relevant in rural areas, where traditional energy infrastructure is limited, and renewable energy can provide critical services. Recent research clearly demonstrates that effective community engagement, public awareness, and visual exposure to renewable technologies can enhance adoption rates [19–21]. These elements are crucial for overcoming barriers such as limited financing and technical challenges, promoting sustainable energy access, and supporting socio-economic development in underserved regions. Consequently, there is a growing interest among scholars, practitioners, and policymakers in understanding factors conducive to renewable energy adoption in rural communities and the role of community engagement in effective energy project management [22–24].

However, there is a notable dearth of studies investigating the specific challenges and mismatches between available Solar PV products and rural community needs, particularly in Africa [25,26]. In Zambia, the adoption of solar energy is hindered by numerous barriers, including the lack of sustainable financing and technical viability of Solar PV mini grids [27]. Following the failure of Mpanta's 60 kW solar mini-grid in northern Zambia, additional deployments - including Magodi (48 kW), Katamanda (52 kW), Chitandika (28 kW), Muhanya (24 kW), and Chibwika (32 kW) - are now also facing critical sustainability issues [27,28]. Although these projects hold potential to improve rural electrification, they encounter significant obstacles to long-term viability. Financial sustainability is a primary issue, as the tariffs necessary to meet capital and operational expenses are often unaffordable for low-income rural residents. Technical challenges also undermine success, with mini-grids frequently suffering from improper sizing, leading to either over- or under-capacity, thus affecting reliability and efficiency [27].

Operational deficiencies intensify these sustainability challenges. Many mini-grids are managed by community or government bodies without adequate technical expertise, leading to inconsistent maintenance and shortened operational lifespans [27,29]. Further, viewing these systems as “donative” rather than commercial ventures limits community engagement and utilization. Misaligned subsidy structures that fail to accommodate stakeholder needs have only worsened these issues, undermining the grids' potential impact [27–29]. Despite global advocacy for renewable energy adoption, Zambia faces unique challenges hindering widespread solar energy use. Specifically, issues with financing and the technical feasibility of solar PV mini grids present significant obstacles [15,30–33]. Addressing these challenges requires focused research and strategic interventions tailored to Zambia. Research from Zambia identifies several factors influencing intentions toward solar energy adoption.

Against this backdrop, this paper seeks to address critical gaps in understanding solar energy adoption in rural Zambia. Specifically, we investigate the influence of social learning on successful technology adoption models in the rural Zambia context, as well as the relationship between exposure to solar technology and adoption intention within three rural communities. Parallel case studies (examining mobile phones, solar phone chargers, solar torches and piped water) from these communities are then presented to contrast perspectives of PV and its adoption with instructive approaches to introducing new technologies into rural communities. By exploring these dimensions, our research aims to contribute to the development of informed policies and interventions designed to promote sustainable energy access and foster socio-economic development in Zambia and similar contexts.

2. Literature review

The intricate relationship between individual perceptions, socio-economic conditions, and policy support plays a pivotal role in driving renewable energy adoption globally. Studies from developing countries globally highlight significant socioeconomic barriers, such as high installation costs and inadequate government financial support [34–36]. In Sub-Saharan Africa (SSA), including Ethiopia and Kenya, similar challenges persist despite policy interventions, emphasizing the need for affordability and effective policy implementation [37,38]. For example, in Malawi, consumers' aspirations for upgraded appliances indicate evolving energy needs, whereas in Rwanda, the use of home solar PV systems for income generation remains limited, pointing to untapped potential [39]. Research on solar PV adoption in Zambia stresses the importance of context-specific factors. In Zambia, attitudes toward solar solutions, perceived benefits, and trust in the technology are significant drivers of adoption, alongside government incentives and social norms [34,40]. Comparatively, in South Africa, individual preferences and social identity are crucial [9,35,41]. In Uganda, energy needs for business operations have less influence on adoption intentions, reflecting diverse adoption dynamics influenced by regional socioeconomic factors [42].

The perceived benefits and affordability of renewable energy adoption present a complex landscape in Sub-Saharan Africa (SSA). Holistic approaches that address technical, financial, and socio-economic factors are necessary for equitable energy access and sustainable development [4,27,29,38,43,44]. The dynamic nature of rural energy needs and the importance of understanding socio-economic benefits are emphasized. Challenges like technical inadequacies, poorly structured tariff charges, and market constraints pose obstacles to the sustainability of renewable energy initiatives, highlighting the need for innovative and integrated policy frameworks [32,37,45,46]. Education and public perception significantly impact the adoption of solar energy technologies in rural Africa. Improving awareness through education about the benefits of clean energy sources is essential for facilitating adoption [47,48]. The narrative underscores the urgent need for renewable energy solutions to address prevalent energy access challenges in developing regions [41].

Social dynamics, including individual decision-making processes, social norms, peer influence, and information dissemination, are critical in solar photovoltaic (PV) adoption. Financial capabilities, attitudes toward green technologies, social norms, and peer behaviors significantly shape adoption behaviors [49,50]. Effective information dissemination and leveraging social capital are pivotal in promoting solar energy adoption, although strategies must be context-specific [49–53]. The role of social influence mechanisms in driving renewable energy adoption is increasingly recognized globally. Peer effects, observational learning, and word-of-mouth communication are crucial in shaping adoption behaviors. Non-price incentives, such as information provision and peer comparisons, effectively accelerate renewable energy technology adoption [53,54]. While empirical evidence from various countries showcases the effectiveness of social influence mechanisms, the Zambian situation is one of persistent energy poverty and limited clean energy access, necessitating further research on peer-based interventions [55].

The literature highlights the significant role of peer effects in driving renewable energy adoption across diverse regions. Peer networks influence adoption behaviors, shape beliefs, and facilitate information dissemination. Social norms and community engagement are crucial for widespread adoption [56]. However, the nature of peer influence varies, with studies from Zambia emphasizing the role of community leaders in alleviating fears and promoting acceptance of renewable energy technologies [55]. Leveraging social mechanisms for promoting sustainable energy adoption focuses on different aspects and contexts. Social learning and peer interactions significantly influence renewable energy adoption at the household level, as seen in Rwanda [57]. Social interactions and peer networks directly influence household decision-making, reinforcing the importance of community dynamics [53].

The adoption of solar energy in rural Zambia faces significant challenges due to the prevalence of counterfeit (fake products or fake labels) products, which negatively impact social dynamics and adoption behaviors. In October 2024, the Zambian government raised concerns over the surge of counterfeit solar products flooding the domestic market, emphasizing the potential risks to the country's solar adoption efforts [58]. Literature supports this concern, showing that counterfeit solar products are prevalent across Sub-Saharan Africa, especially in developing countries where regulatory measures often fall short of effective quality control [59–62]. These substandard products erode consumer trust in solar technology and lead to higher long-term costs, as users frequently face premature replacement needs due to product failure. Counterfeit solar panels have become widespread due to economic constraints, regulatory weaknesses, and low consumer awareness, creating barriers to genuine solar technology adoption [27,59,60]. These issues collectively weaken community trust in solar technologies, which is a crucial component of social influence and peer-led adoption in rural communities [62–64]. Economic barriers are a major driver of this trend. High poverty levels in rural Zambia restrict access to legitimate solar products, leading many consumers to purchase cheaper, counterfeit alternatives [27,65]. This trend undermines social influence, as the adoption of unreliable products can cause dissatisfaction, reducing the likelihood that early adopters will positively influence their neighbors' adoption intentions.

Weak regulatory frameworks further exacerbate the problem, as inadequate enforcement allows counterfeit products to proliferate unchecked. This not only affects consumer confidence but also deters legitimate investors from entering the market, limiting the availability of quality solar options in rural areas [59,60,66]. A lack of community trust, compounded by substandard product performance, hampers positive social learning about solar benefits, thereby reducing adoption potential [67]. While social influence is typically a powerful factor in promoting solar energy adoption, the presence of counterfeit products generates negative social learning effects. To improve adoption rates and community acceptance, Zambia's solar energy market requires targeted regulatory reforms, heightened consumer awareness, and more robust quality controls [68].

Community-based interventions and understanding of socio-cultural contexts are crucial for promoting renewable energy adoption. Studies from West Africa, Sierra Leone, and Zambia emphasize the importance of community engagement for successful renewable energy initiatives. Leveraging trusted community networks, peer consultations, and community-led outreach initiatives effectively accelerate adoption. Addressing socio-cultural, geographic, and market dimensions with custom-made interventions tailored to local contexts and stakeholder perspectives is vital for shaping energy adoption behaviors [9,27–29,56,69,70]. Ward Development Committees (WDC) were introduced to enhance community participation in decision making. WDCs in Zambia are central to fostering community ownership and participation in local development. The National Decentralisation Policy (revised 2013) and the Constitution of Zambia (Amendment) Act No. 2 of 2016 establish a legal framework that supports devolved governance and promotes citizen engagement [71]. Through section 36 of the Local Government Act No. 2 of 2019, WDCs formalise community participation by serving as conduits between local authorities and residents, coordinating community-centered development programs, and leveraging socio-economic opportunities [71]. Despite their importance, WDCs face significant operational challenges. Poor communication with local authorities, limited understanding of their broader functions beyond Constituency Development Fund (CDF) management, and undue political interference hinder their effectiveness. Additionally, the absence of financial incentives demotivates members, who often rely on personal resources to fulfil their roles [72]. A study in Chibombo district found that the operationalisation of most WDCs was poor, with issues such as financial irregularities, political affiliation, and weak adherence to governance guidelines limiting their functionality [73].

Research on solar energy adoption in rural areas consistently emphasizes the powerful role of social influence, particularly through social learning, peer interactions, and communication channels. Social learning, involving both observation and active communication, significantly shapes adoption decisions in various rural contexts. For instance, studies in rural China show that social networks enhance adoption intentions through active discussions, although passive visual observation has a limited effect on its own [74]. In Burkina Faso, household characteristics and the economic activities of communities also modulate adoption decisions, underscoring that social influence is closely intertwined with local economic conditions [75]. These findings highlight social learning as a crucial yet context-specific driver of solar PV adoption.

Peer influence further bolsters adoption, especially when early adopters become visible examples in their communities. In rural Kenya, the adoption rate of solar lanterns reached 96 %, with families reporting a 14.7 % reduction in annual expenses, reflecting how social and economic benefits reinforce adoption [76]. Peer visibility, as observed in Kendu Bay, Kenya, leads to higher adoption rates as new installations inspire further uptake through word-of-mouth recommendations [77]. Additionally, in large-scale interventions leveraging peer interactions, each municipality in the U.S. added 37 installations on average, demonstrating a substantial social learning effect and highlighting the economic advantages associated with adoption [56].

The efficacy of social influence also depends on communication from trusted community figures. Active communication from respected leaders has shown to increase adoption intentions by considerably reinforcing subjective norms around solar PV systems, as observed in China [74]. Economic considerations, including perceived installation costs and the promise of long-term savings, are crucial to adoption, and geographic factors like sunlight access further impact decisions [78].

Studies have found that structured informational campaigns, such as ambassador-led initiatives, increase installations by 37 units per community on average [56], with a critical mass threshold of 12.5 %–15 % optimizing community-wide adoption rates [77]. Together, these studies reveal that social influence, if leveraged effectively, can notably drive the adoption of solar PV technology in rural settings across diverse socio-economic contexts.

Social influence has played a pivotal role in the successful adoption of renewable energy technologies across various regions. Observational learning and peer effects have been instrumental in encouraging the uptake of solar PV systems, particularly when individuals witness their neighbors or community members benefiting from these technologies. For instance, in Malawi, the aspiration for upgraded appliances has driven solar adoption, while in Rwanda, community engagement has fostered the spread of solar home systems. In Zambia, trusted community leaders have been key in alleviating fears and promoting acceptance of renewable technologies. These successes show the importance of leveraging social networks and peer interactions to enhance renewable energy adoption.

The primary message from the literature stresses the significance of social dynamics, community involvement and stakeholder engagement in promoting renewable energy adoption. Despite variations in research contexts and approaches, the emphasis on individual benefits, user-friendly technologies, community ownership, and addressing psychological barriers remains consistent. Holistic approaches, long-term development investments, and ethical research practices are essential for sustainable energy transitions. Enhancing knowledge dissemination and community consultation can facilitate broader adoption of renewable technologies, contributing to sustainable poverty alleviation and community empowerment.

3. Theoretical underpinnings/models to inform the study

The current study sets out and utilizes the new Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) to help explain the degree to which social learning is observed in solar PV adoption. (See Fig. 1) RUDSHAM integrates three main theoretical frameworks to understand the factors influencing the adoption of renewable energy technologies in rural areas. It combines the Technology Acceptance Model (TAM), Diffusion of Innovations Theory, and Theory of Planned Behavior (TPB) to focus on internal factors affecting adoption willingness. TAM highlights performance expectancy, effort expectancy, social influence, and facilitating conditions as key drivers of technology adoption [79–82]. Diffusion of Innovations Theory explains the stages and factors influencing the spread of new technologies over time [79]. TPB suggests that behavioral intentions are shaped by attitudes, subjective norms, and perceived behavioral control [82]. Additionally, RUDSHAM incorporates Social Learning Theory, which emphasizes the

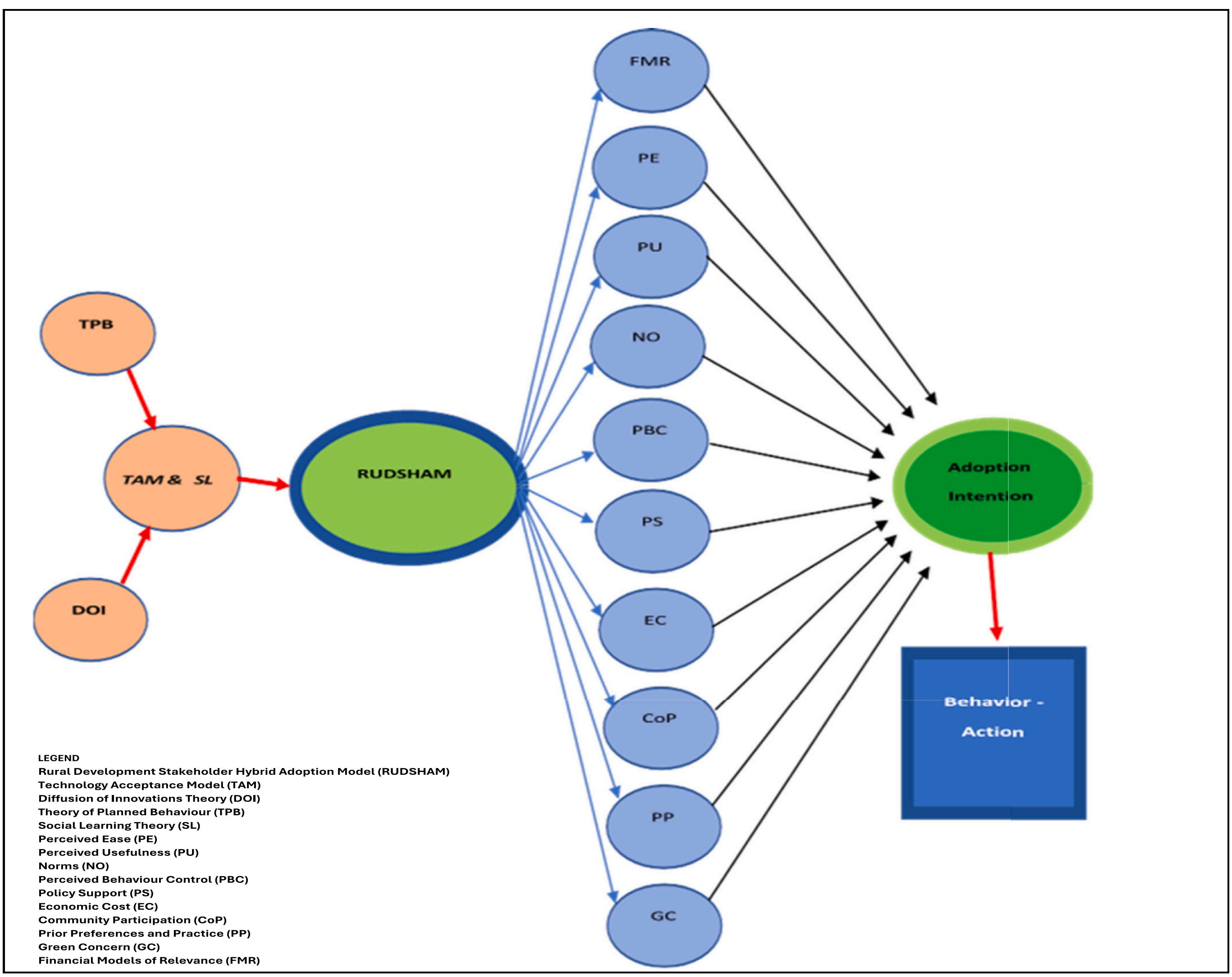

Fig. 1. RUDSHAM Hybrid Adoption Model.

role of observation and imitation in shaping attitudes and adoption decisions [83]. Social dynamics, such as peer effects and active communication within social networks, significantly influence individuals' decisions to adopt renewable energy technologies. The social learning concepts that shape individual behaviors and societal norms within communities can be divided into social influence, peer influence, neighbor influence, community influence, and social dynamics. Social learning involves acquiring knowledge, behaviors, and attitudes through observing and interacting with others in the social environment [7,38]. It reflects the broader cultural and societal context within which individuals are embedded and highlights how community-level factors shape, inform and influence individual behaviors and attitudes. Social dynamics, on the other hand, refer to the patterns, processes, and changes in social interactions and relationships within a given social system over time [39,40]. This provides a framework for understanding the complexity and confluence of different social forces.

By combining internal factors from TAM, Diffusion of Innovations Theory, and TPB with external influences from Social Learning Theory and peer effects, RUDSHAM offers a comprehensive understanding of the multifaceted factors driving renewable energy adoption in rural developing areas. This holistic approach recognizes the complex interplay between individual beliefs, social influences, and community dynamics in shaping adoption behaviors. The framework provides valuable insights for policymakers, researchers, and practitioners aiming to promote sustainable energy transitions. RUDSHAM's alignment with a mixed-methods research approach, including in-depth interviews, focus groups and observations, ensures a thorough examination of solar PV adoption in rural Zambia. This integration of theoretical and methodological rigor offers a robust foundation for investigating the complex factors impacting solar PV adoption, facilitating the development of effective strategies for sustainable energy development.

3.1. Rural development stakeholder hybrid adoption model (RUDSHAM)

RUDSHAM provides a comprehensive framework to understand how social learning, social influence, community influence, and observational learning contribute to the adoption of solar PV in rural areas of Zambia. Below is a description of how each attribute of the RUDSHAM framework highlights these influences. The rate of innovation is influenced by several key attributes with social influence embedded within this:

3.1.1. Perceived ease (PE)

- **Definition**: Encompasses the ease of installation, use, maintenance, and access to experts for support.
- **Social Learning/Influence**: Observing others successfully install and maintain solar PV systems can ease concerns about complexity. Peer demonstrations and shared experiences lower perceived barriers, enhancing community confidence in adopting the technology. Research shows that perceived ease of use significantly influences technology adoption [81].

3.1.2. Perceived usefulness (PU)

- **Definition**: Factors include the technology's dependability, reliability, energy security, improvement over existing power sources, and productive use.
- **Social Learning/Influence**: Seeing the tangible benefits and improvements in the quality of life for early adopters can convince others of the utility of solar PV. Word of mouth and visual evidence of usefulness can be powerful motivators. The Technology Acceptance Model emphasizes the importance of perceived usefulness in adoption decisions [80].

3.1.3. Norms (NO)

- **Definition**: Compatibility with social norms, household norms, social acceptability, and the influence of people's opinions and experiences.
- **Social Learning/Influence**: Social norms and peer influence play crucial roles. If solar PV is seen as socially acceptable and beneficial within the community, others are more likely to adopt it. Studies highlight the impact of social norms and peer pressure on environmental behaviors [84].

3.1.4. Perceived behavior control (PBC)

- **Definition**: The availability of return warranties, choice in configuration, guarantees, and the freedom and ability to choose to buy.
- **Social Learning/Influence**: Observing others' ability to control their solar PV usage and experience with warranties and guarantees can empower individuals to feel capable of managing the technology themselves. Ajzen's Theory of Planned Behavior emphasizes the role of perceived behavioral control in intention formation [82].

3.1.5. Policy support (PS)

- **Definition**: Includes incentives, subsidies, government support, alignment with UNSDGs, support from solar PV suppliers, and effective communication.
- **Social Learning/Influence**: When communities observe successful policy-supported initiatives, it reinforces the perceived legitimacy and safety of adopting solar PV. Government endorsements and subsidies can catalyze adoption through observed successes [79,85].

3.1.6. Economic cost (EC)

- **Definition**: The price of solar PV systems and its impact on the decision to buy and overall energy expenditure.
- **Social Learning/Influence**: Learning about the economic benefits and long-term savings from peers who have adopted solar PV can mitigate cost concerns. Cost-benefit analyses shared within the community can promote adoption [86].

3.1.7. Community participation (CoP)

- **Definition**: The extent of community ownership and involvement in designing, financing, and maintaining solar PV systems, as well as supplier engagement.
- **Social Learning/Influence**: High levels of community participation enhance collective learning and support structures, making adoption more likely. Community-driven projects often succeed due to shared responsibility and mutual support [87,88].

3.1.8. Prior preferences and practice (PP)

- **Definition**: Current energy practices, preferences, key uses of energy, reasons for these preferences, and expectations.
- **Social Learning/Influence**: Observing peers transition from traditional energy sources to solar PV can shift preferences and practices, demonstrating viability and efficiency in the local context. Prior successful adoptions serve as a blueprint for others [89].

3.1.9. Green concern (GC)

- **Definition**: Environmental concern and awareness of the impact at individual, household, and community levels.
- **Social Learning/Influence**: Seeing peers adopt solar PV for environmental reasons can heighten awareness and concern,

encouraging others to follow suit. Environmental motivations often spread through social networks [90].

3.1.10. Financial models of relevance (FMR)

- **Definition**: Comparison of current finance practices with other relevant solar PV financial models globally and their applicability in the developing world context.
- **Social Learning/Influence**: Exposure to successful financial models and practices in similar contexts can influence local adoption by demonstrating financial viability. Observational learning of how financing can be managed effectively is crucial [31,91,92].

3.2. RUDSHAM informing methodology

The data collected aims to inform an understanding of social influence on solar PV adoption in rural Zambia by examining various aspects of community dynamics and individual perceptions. Through in-depth interviews and focus group discussions, the researchers explored perceived ease of use, perceived usefulness, social norms, and economic factors. By analyzing these dimensions, the study revealed how observing peers, learning from community leaders, and understanding financial models and policy supports, informs and impacts upon individuals' decisions. This comprehensive approach highlights the role of social learning and peer influence in facilitating the acceptance and uptake of solar PV systems, providing insights for targeted interventions.

A methodology based on the ten attributes of the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) theory provided a detailed understanding of social influence on solar PV uptake in rural Zambia. Each attribute of the RUDSHAM theory contributed to revealing the social dynamics and factors affecting solar PV adoption.

3.2.1. Perceived ease (PE)

Researchers collected data on the ease of installation, use, and maintenance of solar PV systems. By analyzing responses from community members, they understood how user-friendly the technology was perceived to be and identified any barriers related to technological complexity that impacted adoption.

3.2.2. Perceived usefulness (PU)

The research team assessed the perceived benefits of solar PV systems, such as reliability and energy security, by gathering community feedback. This helped them understand how the practical advantages of solar PV influenced community acceptance and trust in the technology.

3.2.3. Norms (NO)

By examining social and household norms, as well as the opinions and experiences of influential community members, researchers uncovered the significant role of social learning and peer influence. This analysis identified key opinion leaders who had the potential to promote solar PV adoption within their communities.

3.2.4. Perceived behavior control (PBC)

Data on perceptions of control over the purchase and usage of solar PV systems, including the availability of warranties and configuration options, were gathered. This provided insights into how perceived autonomy and control affected decision-making processes regarding solar PV adoption.

3.2.5. Policy support (PS)

Researchers evaluated the impact of government incentives, subsidies, and supplier support on solar PV adoption. This examination illustrated how external facilitation and effective communication of policies influenced community adoption rates.

3.2.6. Economic cost (EC)

By analyzing the economic cost of solar PV systems and its impact on household budgets, the research team understood how financial considerations played a crucial role in the decision to adopt solar PV technology.

3.2.7. Community participation (CoP)

The level of community involvement in the design, financing, and maintenance of solar PV systems was assessed. This highlighted the importance of collective action and ownership in sustaining the adoption of solar PV technology.

3.2.8. Prior preferences and practice (PP)

Researchers investigated existing energy practices, preferences, and key uses of energy within the community. Understanding these factors provided a baseline against which the potential shift to solar PV could be measured.

3.2.9. Green concern (GC)

Data on environmental concern and awareness at the individual, household, and community levels were collected. This helped researchers gauge the extent to which environmental motivations influenced the decision to adopt solar PV.

3.2.10. Financial models of relevance (FMR)

The research team compared current finance practices with other relevant solar PV financial models globally. This comparison highlighted the applicability and potential impact of different financial approaches on solar PV adoption in rural Zambia.

Each attribute of the RUDSHAM framework emphasizes different aspects of social learning, social influence, community influence, and observational learning. Together, they provide a holistic view of how these social dynamics facilitate the adoption of solar PV in rural Zambia, illustrating the importance of community involvement, perceived ease and usefulness, social norms, economic considerations, and supportive policies in driving sustainable technology adoption.

4. Research methodology: Research strategy and data collection methods

By integrating data from the ten attributes set out in the previous section of the paper, the RUDSHAM-based methodology offered a comprehensive understanding of how social norms, perceived benefits, economic considerations, policy frameworks, and community involvement collectively influence the adoption of solar PV systems in rural Zambia. This approach enabled stakeholders to design targeted interventions that leveraged social influence to promote sustainable energy solutions.

The research was conducted over 6 months (October 2022 to March 2023) across 3 remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), and Chongwe Rural (Lusaka Province). These locations were strategically chosen for their relative isolation and lack of access to the national power grid. A 4-week pretesting pilot study was conducted with 5 participants in Luano village (Chingola Rural, Copperbelt Province) to ensure the validity and reliability of the research instruments. One research assistant, fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), facilitated data collection. The primary investigator is also fluent in English and has a working knowledge of Bemba, Nyanja and Lamba.

The data collection involved in-depth interviews, ranging in duration from 30 min to 60 min, with 39 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymakers. Additionally, 7 focus group discussions (FGDs), each comprising 8 participants from the selected rural areas (3 from Kapiri, 2 from Mkushi and 2 from Chongwe), were conducted to capture a range of opinions and views from the communities. To address gender sensitivity and dominance issues in FGDs, sessions were facilitated by village 'headmen' or councillors, taking advantage of their trusted positions within the community. Mixed and separate discussions ensured diverse perspectives from both men and women, with participants receiving refreshments and tokens of appreciation.

Recorded interviews and photographs, taken with consent, were securely stored on Reading University's (UK) OneDrive cloud account with protected access to ensure data security. Data analysis involved coding interview transcripts, using NVIVO 14, into specific themes and extracting relevant direct quotations to supplement structured interview data. A pilot study interview was conducted resulting in minor adjustments to the protocol based on the pilot results. This multifaceted qualitative approach, including in-depth interviews, FGDs, photovoice, and observations, ensured the validity and reliability of findings by representing various stakeholder viewpoints.

Ethical approval and informed consent protocols were strictly adhered to, ensuring the study's compliance with ethical standards. By integrating the RUDSHAM framework with rigorous research methods, the study provides valuable insights for policymakers, researchers, and practitioners focused on promoting sustainable energy transitions in Zambia and other developing countries.

5. Research findings

The empirical data findings in this study examine the critical role of social learning in the adoption of solar PV technology in rural Zambia. Evidence presented in the findings demonstrates how social learning, through observational learning and neighbor influence, shapes community interest and willingness to engage with solar PV (See Tables 1–7). Specifically, the findings showcase various motivations, such as community members' desire for improved energy access and economic opportunity, while also addressing barriers, including economic constraints and limited technical knowledge, which affect the adoption process. These dynamics are analyzed within the rural Zambian context, where peer influence and visible examples of successful PV installations provide significant social learning cues that encourage adoption. Further detailed direct quotations are provided in Appendix 4.

5.1. Social influence dynamics

Empirical findings highlight the organic adoption of solar technology in rural areas, driven primarily by peer influence, exposure, and practical benefits (See Table 1). Observing neighbors' solar systems for lighting, irrigation, and phone charging encourages wider adoption. Households often acquire systems through informal loans, savings, or family support. Children also play a role by urging parents to improve living conditions. The spread of solar energy knowledge occurs through community interactions rather than formal programs, as no aid agency distributes solar panels or mobile phones. This self-driven uptake shows the perceived value of solar technology. Once benefits are realized, households willingly invest in upgrades, fostering increased productivity and economic resilience. Community-led diffusion has proven effective in driving solar adoption and improving rural livelihoods.

When individuals learn or observe behaviors or habits that are beneficial to others, especially those they closely associate with, they are highly likely to be influenced to engage in similar behavior. Individual desires ultimately drive community adoption when aggregated. This underlines the power of observation and peer influence. Initially, when individual community members have not observed or experienced the benefits of some services or products, they may question the need to pay but this perception changes as soon as there is an understanding and appreciation of the product/service benefit.

Table 1
Social Influence Dynamics Direct Quotations.

Participant	Aspect	Representative Illustrative Quote
Mkushi Interview 4	*Social Influence*	*"I observed that the houses of my neighbors had good lighting systems and out of interest, I inquired. I discovered you could get a system through a loan and pay slowly over two years through the mobile telecommunication companies. I did not hesitate and quickly organized some funds, and now I do not have to sleep in the dark and be afraid of being bitten by poisonous snakes."*
Chongwe Interview 4	*Social Influence*	*"I have a solar system that helps me with irrigation. I got the idea from my friend who could grow crops during the dry season. I was shocked and excited at the discovery. I found out the price and the source, organized resources through selling some of my produce, and my children in the city also helped. Now I can enjoy winter maize and water my garden. It also helps me raise income."*
Kapiri Discussion (FGD) 2	*Social Influence*	*"We have come to learn about various systems of solar energy that can be used for irrigation, lighting, and phone charging through intermingling with each other, and now, in this village, everyone has at least one solar-powered gadget or another. The knowledge of solar energy devices has been spreading like wildfire around the whole village."*

5.2. Community engagement deficit

Empirical evidence demonstrates that development projects often suffer due to inadequate community consultation and context alignment (See Table 2). Free stoves, promoted for efficiency, were largely unused as they failed to meet local cooking needs, reflecting a lack of engagement in design and implementation. Rural farmers express frustration with urban-based decision-making, disconnected from rural realities. Political engagement on solar energy is minimal, leaving awareness primarily through informal channels. Community members stress the value of local input for project success but are often sidelined, leading to failure. Aid agencies' interventions, focused on immediate aid over sustainable development, are perceived as wasteful or poorly planned.

Solar panels are widely accepted within the community as a reliable source of energy. Community members highlighted that consultation plays a crucial role in the design and implementation of solar projects, ensuring alignment with local needs and preferences. Ongoing

Table 2
Community Engagement Deficit Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 4	*Lack of Community Involvement*	*"They brought some free stoves that they claimed used less firewood. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money…or maybe someone from the higher offices benefited economically from them, you never know."*
Kapiri Discussion (FGD) 1	*Lack of Community Involvement*	*"We can all testify here that you are the first person who has come to interview and talk to us about solar. We just learn about solar energy from our neighbors and when we visit the city or some white farmers' houses."*
Mkushi Discussion (FGD) 2	*Lack of Community Involvement*	*"We might be uneducated, but there is something we can offer, especially pertaining to projects that are implemented in our villages. We know better because we have lived here all our lives, but we are not involved at all, which causes many projects to fail."*

engagement and feedback mechanisms facilitate continuous improvement and expansion of solar initiatives, although challenges related to infrastructure funding may impede scalability and inclusivity. Unfortunately, no collaboration or consultation with the community was identified at the time of this research, which poses a great risk to the sustainability of solar projects because the intended project beneficiaries are not sufficiently involved in building a strong sense of ownership.

5.3. Ownership and sustainability

Findings highlight a lack of community consultation in development projects, resulting in limited ownership, neglect, and vandalism (See Table 3). Free projects often fail without community investment or accountability mechanisms. Rural people feel disconnected from externally planned initiatives, contributing to apathy and misuse. Conversely, projects with community involvement—such as primary school construction—foster pride and sustainability. Contributions to water systems through payments and labor reflect a willingness to engage when there is ownership and responsibility. The breakdown of poorly managed government-provided assets, such as solar hammermills, illustrates the ineffectiveness of top-down approaches. While free projects are appreciated, they lack durability and long-term success without proper management and community participation.

Historically, communities have become reliant on external aid, resulting in a cycle of dependency where aid agencies provide infrastructure without establishing mechanisms for sustainable maintenance (Observation of the interviewees). This approach leads to a high rate of project failure and nonfunctional infrastructure in the long term. Encouraging communities to take ownership of projects fosters a sense of responsibility. Rather than perpetuating the narrative of poverty and dependence, empowering communities to contribute financially instils a sense of worthiness and agency. This engagement may open up opportunities for novel financial arrangements for emerging technologies at either the community or individual level.

5.4. Solar quality challenges (counterfeits)

Empirical evidence highlights significant issues with solar product quality, particularly due to an influx of low-cost and counterfeit products, often from China, leading to frequent product failure and financial losses for rural consumers (See Table 4). Vendors and shops commonly refuse returns, leaving consumers unable to repair broken gadgets. Affordability pressures, worsened by poor agricultural seasons, drive rural communities to purchase subpar products that quickly break. Counterfeit solar panels are pervasive, with many containing non-functional or purely decorative parts, deceiving buyers about their true capacity. While reputable dealers provide quality products, they are less accessible. Commercial farmers typically avoid counterfeits and use high-quality sources, but rural users often rely on counterfeits, acknowledging their limitations yet accepting their utility due to limited options.

Table 3
Ownership and Sustainability Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Kapiri Interview 2	*No sense of ownership.*	*"No one consults us. They just implement projects that are already designed elsewhere. Hence, most people, to be honest, do not feel a true sense of ownership at the individual or community level. That's why there is a lack of care, stealing, and vandalism."*
Mkushi Interview 2	*No sense of ownership.*	*"Who is supposed to watch over the free projects that are implemented in our villages? Is it the headman or the community? It's like it's no one's business, and if there is no one to watch over something, it dies naturally. It's like a motherless baby… it can't survive… Ha ha ha."*
Kapiri Discussion (FGD) 2	*No sense of ownership.*	*"We feel like the primary school in the village is part of our own property because, when it was being constructed, each household had to contribute building blocks and other materials that we could manage. It's not much but I feel proud to have contributed and now my children can go to school without walking many miles. The headman and elders coordinated the contributions."*

Table 4
Solar Quality Challenges (Counterfeits) Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 2	*Counterfeits*	*"The solar panels I have are very big but not very powerful. When my brother from the city visited, he told me that most of the panel was just decoration and only a small part was used for solar production."*
Kapiri Discussion (FGD 2)	*Counterfeits*	*"Most of us keep buying new solar gadgets every now and then because most of them are Chinese. We have disposed of a lot of them…ha ha…but what can we do? The counterfeits are affordable."*
Mkushi Discussion (FGD 1)	*Counterfeits*	*"Most of us, because of a poor farming season, just buy the cheapest and most affordable gadgets we can find on the market, and sadly, cheap is expensive. But honestly, we have no option. And when these gadgets break, there is no way to repair them, so it's a loss."*

Effective communication regarding solar panel availability, the need for expertise, and the risk of counterfeit products is essential to supporting successful solar PV adoption in rural communities. The ready accessibility of solar panels through numerous local shops highlights the widespread availability of this technology. However, the perceived prevalence of counterfeit and substandard panels remains a significant issue, as consumers often struggle to differentiate between genuine and inferior products; peer information dissemination of this issue serves to undermine trust in PV technology. In this context, rural farmers, typically highly price-sensitive, are particularly susceptible to purchasing unreliable or ineffective solar products, especially without established consumer standards for product quality.

Data gathered in this study supports the presence of social learning mechanisms to address these challenges. Community members increasingly share information on which dealers offer reliable products, providing informal guidance that emphasizes the importance of quality assurance and expert consultation. Observational learning within the community also plays a role, as individuals observe and adopt the practices of others who successfully use solar technology sourced from reputable suppliers, reinforcing a cautious yet proactive approach to PV adoption.

5.5. Entrenched poverty and tradition

Findings indicate deep-rooted feelings of neglect and marginalization in rural communities, leading to resignation about poverty and skepticism toward external aid (See Table 5). Traditional practices in medicine, agriculture, and family structures are valued, with some resisting modernization and outside intervention due to perceived disrespect. Education is seen as secondary to family-building, although there is recognition of its potential. Shifting from a post-paid to a prepaid water system showed positive changes in engagement, highlighting the importance of self-initiative. Generational cycles of poverty create mental barriers, with defense mechanisms that protect but can hinder progress. Encouragement and exposure to opportunities can help individuals break these cycles and foster growth.

A number of commercial farmers highlighted the need to address cycles of poverty through a shift in mindset, as they perceived that deeply ingrained attitudes and self-defense mechanisms often hinder progress. Commercial farmers cited a "poverty mentality", described as

Table 5
Entrenched Poverty and Tradition Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Kapiri Interview 1	*Community Negative Mindset*	*"We were born in poverty, grew up in poverty and we will probably die in poverty together with our children because no one cares about us including our own leaders."*
Chongwe Interview 2	*Community Negative Mindset*	*"I don't need assistance from anyone as I have managed to live and survive using the knowledge that I have acquired from within the community. I do not need to be modern or to learn anything extra."*
Kapiri Discussion (FGD) 2	*Community Negative Mindset*	*"We have traditional systems that have worked for us in the areas of medicine, marriage, agriculture, sustainability for hundreds of years which we will hold on. Someone can't just come from outside and tell us what to do. That is disrespectful and offensive. That's why even projects from aid agencies fail."*

a complex phenomenon, limiting both material resources and rationale processes, preventing individuals from seizing advancement opportunities. They went on to suggest that interventions by aid agencies frequently overlook mindset issues while aiming to remain sensitive to the physical contexts of adopters. They suggest that the oversight of prospective user rationale undermines the effectiveness of development programs. It was suggested that a holistic approach to poverty alleviation must address both material needs and psychological barriers. Comprehensive education on poverty and rural people's mindsets is crucial yet often neglected, leaving donors with a superficial understanding of poverty's complexities. Effective poverty interventions must integrate strategies for mindset transformation with traditional development initiatives, recognizing the interplay between material resources and mental attitudes in fostering sustainable change.

5.6. Aid effectiveness and the importance of sustainability

Findings indicate that many aid agencies fail to address poverty's psychological and attitudinal roots, fearing political backlash (See Table 6). Their reluctance to make communities pay for services like solar and water systems results in unsustainable outcomes, with broken infrastructure often left unmaintained after funding ends. Donors often prefer providing free aid to meeting targets, overlooking self-sustaining models. This approach fosters dependency and undermines community autonomy. In contrast, communities value services they invest in, finding ways to pay for necessary repairs. Aid agencies frequently opt for short-term solutions over sustainable, business-oriented approaches due to donor resistance and lack of nuanced understanding. There is criticism that donor motivations are often self-serving, preferring emotionally appealing free aid over meaningful, skill-based support that builds self-reliance and dignity. Donors, often uninformed about the complexities of poverty, may prefer to address immediate needs without considering the long-term implications. This results in a reluctance to invest in initiatives that require sustained support, perpetuating the dependency syndrome rather than fostering self-sufficiency. By recognizing the value of important lifesaving services and actively seeking ways to afford them, individuals are motivated to increase productivity and pursue economic opportunities. Acknowledging the worth and capabilities of community members is essential for preserving dignity and promoting self-esteem. Offering services for free can undermine the perceived value of individuals and perpetuate cycles of dependency.

Table 6
Aid Effectiveness and the Importance of Sustainability Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Commercial Farmer Interviews 2	*NGO Mindset*	*"One of the biggest failures of the NGO community is their reluctance to address the mindset issue. They avoid it, partly because they fear appearing politically incorrect. This hesitance undermines aid programs, as they do not tackle the deeper roots of poverty, many of which stem from mental and attitudinal barriers."*
Commercial Farmer Interviews 7	*NGO Mindset*	*"We frequently clash with large donor agencies like UNICEF, World Vision, and USAID over making communities pay for services. Questions like who will fix a broken pipe or replace a solar panel remain unresolved when systems are provided for free. This lack of sustainable planning is a major issue."*
Commercial Farmer Interviews 16	*NGO Mindset*	*"NGOs often install free systems but do not stick around once their funding ends. This leads to high failure rates, as evidenced by communities where over 70 % of boreholes are nonfunctional. Sustainable solutions require a consistent revenue source, meaning communities must pay for services like solar electricity to ensure lasting success."*

Cultivating a culture of contribution and reciprocity enhances community resilience and self-sufficiency. When individuals recognize the value of their contributions, they are more inclined to participate actively in initiatives aimed at improving their quality of life. The importance of recognizing and respecting the inherent value of an individual's contribution cannot be over emphasized. This is because by valuing the contributions of community members and fostering a culture of mutual respect, initiatives can effectively promote sustainable development while preserving human dignity.

5.7. Project misalignment and dead aid: Challenges of implementation

Findings highlight a lack of meaningful consultation and follow-up in rural aid projects (See Table 7). Solar PV initiatives remain underdiscussed, while political campaigns focus narrowly on farming and water needs. Equipment distributed to farmers often goes unused or poorly maintained due to inadequate training. Free stoves with insufficient heat fail to meet community cooking needs, and mosquito nets are misused due to limited education. Aid projects, such as women's loans, lack necessary training and oversight, leading to poor outcomes. Schools and clinics are built without essential support staff, and livestock distribution efforts falter without veterinary care. Community needs and practicalities are often overlooked, leading to misaligned, wasteful, or underutilized projects.

There is often a disconnect between the needs of the recipient community and the offerings of government officials and aid agencies. The self-serving nature of much humanitarian giving raises the critical need to distinguish between providing aid and investing in sustainable development. Donors may give to fulfil personal satisfaction without a genuine interest in the long-term impact of their contributions. Consequently, aid organizations may prioritize short-term relief efforts over sustainable development initiatives. Disparities in resource allocation within aid organizations highlight systemic issues that hinder long-term development. While immediate relief efforts receive substantial funding, initiatives aimed at encouraging sustainable solutions often struggle to secure adequate support. This discrepancy undermines efforts to empower communities and promote self-reliance.

6. Case studies of technological adoption despite resource scarcity

A number of case studies were raised during the primary data collection that emphasize their relevance for future rural PV adoption as it pertains to social learning. These focused on similar technological interventions as they are either emerging or infrastructural, as well as being adopted in rural areas. These included mobile phones, solar PV chargers, PV torches, and piped water.

Table 7
Project Misalignment and Dead Aid: Challenges of Implementation Direct Quotations.

Participant	Challenge	Representative Illustrative Quote
Chongwe Interview 4	*Misaligned Aid.*	*"They brought some free stoves that they claimed used less firewood. Although we all got the stoves, we do not use them because they cannot cook our food like charcoal or firewood due to insufficient heat. The only reason we accepted the so-called improved braziers was because they were free. No one consulted us when creating the braziers. NGOs (aid agencies) are in the habit of wasting money… or maybe someone from the higher offices benefited economically from them, you never know."*
Kapiri Discussion (FGD 1)	*Misaligned Aid.*	*"Some of the projects that have been implemented here are good, but again there are many projects which are clearly misaligned and have just been a waste of time and money. For example, health programs for distributing mosquito nets ended up with nets being used for fishing because of a lack of adequate training. Loans were given to many women without adequate financial literacy training, resulting in misuse of funds and difficulty in repayment."*
Mkushi Discussion (FGD) 1	*Misaligned Aid.*	*"We received free energy-saving braziers that were distributed in various villages but ended up being unused due to insufficient heat for cooking local staple foods like maize meal (nshima), which requires high temperatures. Schools were built without accompanying teacher housing or water and sanitation facilities, causing high teacher turnover and limited utilization of the infrastructure. Yes, the buildings are there, but there are no teachers. There are clinics but no doctors. There are bee-keeping training programs that were introduced as a source of livelihood, but people sometimes struggle to sell the honey due to difficulties in accessing markets."*

6.1. Mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches

The first illustration (refer to appendix 2 for details), comes from mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches. The overwhelming majority (>80 %) of rural people engaging in focus groups and semi-structured interviews in the four regions covered own mobile phones, solar PV phone chargers, solar PV lighting systems and/or solar PV torches. Further, a substantive share (around 20 %) owns smart phones. In addition to being able to pay for the initial devices, rural people surveyed were also able to pay for ongoing usage, (e.g., prepaid airtime). As noted earlier, no land lines are available in rural Zambia and mobile phone communication towers have negated the use of landlines and leapfrogged their usage [93–95]. The findings emphasize the significance of social learning in promoting the adoption of solar energy technologies, including solar PV chargers and solar lights/torches, among rural farmers in Zambia.

The cultivation of social networks among community members reinforces the importance of collective experiences, thus contributing to the broader uptake of solar technologies in rural settings and illustrating the intersection of social norms and practical needs in fostering sustainable energy solutions. The observed benefits of mobile phones, solar PV phone chargers, solar PV lighting systems, and solar PV torches in rural Zambia emphasize the importance of social learning in technology adoption, which can similarly drive solar energy initiatives. Community members' success stories regarding improved connectivity, enhanced safety, and increased productivity illustrate how witnessing positive outcomes among peers encourages collective interest and adoption of such technologies.

6.2. Piped water adoption in rural setup

Another pertinent illustration (please refer to Appendix 3 for further details) comes from piped water adoption. Literature has shown that on average rural Zambians live on less than $1.9/day [96–98]. However, from discussions in interviews with the director of the aid agency Access Water for Zambia, it was claimed that, as of 2023, over 85 % of rural people in a case study (Samfya rural and Mbabala Island) area were connected to piped water systems (Regional Program Manager, Access Water for Zambia (Water4), Samfya, Luapula Province). Most of these households (~1200) were on prepaid meters and $40,000 (the equivalent of 125,000 l) in annual sales in the 2022/23 financial year (or ~ $33 per household per year on average) was collected. The observed benefits of piped water systems in rural areas underscore the significance of social learning in technology adoption, which can be applied to solar energy initiatives. The success stories shared by community members regarding improved health, reduced disease incidence, and enhanced daily productivity illustrate how witnessing the positive outcomes of peers fosters a communal desire for similar advancements, such as solar PV chargers and lights. These narratives build trust and confidence among residents, motivating them to adopt solar technologies as they perceive these innovations as valuable solutions to their energy challenges, analogous to the acceptance seen in water system implementations.

These case studies demonstrate that if the correct drivers for adoption are established, lower income rural people can find the means to pay for new technologies and their associated services to receive substantive and observable benefits. Elaboration on the lessons that can be taken from these with respect to social learning are discussed below.

7. Interpretation and discussion

7.1. Observational learning and peer influence

From the focus groups and interviews carried out, many participants identified peer learning aspects that led to their adoption of PV or their learning about PV as a useful and helpful technology. The role of peer influence and observational learning in technology adoption has been widely acknowledged in literature. For instance, studies have shown that observing peers who benefit from a new technology significantly impacts an individual's decision to adopt that technology [79,85]. The rapid uptake of mobile phones in rural areas, which bypassed traditional landline infrastructure due to their user-friendly nature and relative infrastructural simplicity exemplifies this phenomenon. In the case of mobile phones, users in this research have identified several clear benefits (see appendix 2) which were readily observable for other prospective users to understand and learn from. For instance, when mobile phones were seen to facilitate market access for agricultural commodities, these experiences and benefits were readily shared among community members exemplifying social influence phenomenon. This aligns with the RUDSHAM attribute of Perceived Ease (PE), where technologies perceived as easy to use are more likely to be adopted. Contrastingly, some research suggests that while peer influence is significant, it must be accompanied by adequate infrastructure and support systems to sustain long-term adoption [99]. This highlights the need for comprehensive strategies that not only leverage social influence but also ensure supportive environments for solar PV adoption in rural Zambia.

Meanwhile, the negative experiences shared by peers, such as counterfeit PV panels, could serve to undermine the adoption of drivers as rural dwellers are less likely to engage in risky purchasing. Given the long-term investment required for PV and the substantial outlay of income relative to mobile phone technology, trust and quality control may be even more important in the case of PV due to the greater risk involved. This aligns with findings from extant literature [60].

7.2. Dependency and sustainability

For successful adoption to occur, intrinsic motivation at both the individual and community levels is essential, as demonstrated in the case studies of mobile phones, piped water systems, and other solar technology devices. Additional information on aid dependency and the sustainability of aid initiatives is provided in Appendices 2 and 3 of the supplementary material. The issue of dependency on external aid and the resulting unsustainable infrastructure is well-documented. Studies indicate that reliance on government and aid agencies' interventions without local involvement often leads to project failures [7,100–102]. Encouraging community ownership (Community Participation) is essential for sustainable development. Involving local communities in the planning and maintenance of projects can foster a sense of responsibility and ensure long-term functionality as evidenced in the mobile phone and piped water adoption case studies. This perspective is supported by recent research emphasizing the importance of local engagement and ownership in successful development projects [87,102]. However, some critics argue that without substantial initial external investment and technical support, community-driven projects may struggle to achieve scalability and impact [30,103]. This underscores the need for a balanced approach that integrates both external support and community involvement for sustainable solar PV adoption.

7.3. Mindset transformation and poverty

Several interviews highlighted the psychological aspects of poverty as a crucial barrier for fostering sustainable development. Previous research emphasizes that ingrained mindsets around being trapped in poverty, an entitlement of support from stakeholders who are perceived to be more affluent, and self-defense mechanisms when support is withheld can hinder progress, making mindset transformation a vital component of development strategies [104]. Integrating these strategies with traditional development efforts can significantly enhance outcomes. For example, in rural Zambia, CARE International implemented the Village Savings and Loan Association (VSLA) program to address poverty mindsets by fostering financial self-reliance among participants [105,106]. Additionally commercial farmers interviewed suggest that they are helping rural farmers to cut out middlemen and add value to their products to increase the profits. This aligns with the RUDSHAM attribute of Perceived Behavioral Control (PBC), where individuals' perceptions of their ability to influence outcomes affect their engagement in development initiatives. However, this approach is often overlooked due to fears of “political incorrectness” or the desire to correct disparities such as historic colonial oppression leading to current poverty or to disparities associated with rural/urban wealth distribution [107–109]. Critics argue that focusing on psychological aspects alone without addressing structural (i.e., psychological) and economic barriers may not yield substantial results [110]. Therefore, a comprehensive approach that addresses both psychological and structural factors will be essential for effective solar PV adoption in rural Zambia.

7.4. Donor motivations and sustainable investments

Despite some positive examples of aid agencies performing well, such as OXFAM (funded by DFID), which implemented a five-year project in communities within the Copperbelt Province - achieving sustainability outcomes through the multi-sector forum model approach, later scaled up by the Zambian government - another issue highlighted in the findings is the perception that some aid agencies prioritize immediate relief over long-term sustainability. This approach has been criticized for perpetuating ineffective aid models [66]. This was reviewed from the findings where many USAID projects had taken off well only to fall shortly due to lack of practical sustainability plans. Treating development services as commodities and empowering communities to invest in their own progress can lead to more sustainable outcomes, as suggested by recent literature [111]. This aligns with the RUDSHAM attribute of Policy Support (PS), emphasizing the need for policies that promote community investment and self-sufficiency. However, some argue that immediate relief is necessary to address urgent needs and that long-term strategies should complement rather than replace short-term aid [112]. This calls for a balanced approach that integrates immediate relief with strategies for long-term sustainability in promoting solar PV adoption.

7.5. Information dissemination and community consultation

Effective dissemination of information and community consultation are crucial for technology adoption. Limited marketing efforts and reliance on informal knowledge channels hinder widespread adoption, as evidenced in recent studies [86]. Engaging communities in the design and implementation of projects ensures that local needs and preferences are met, encouraging greater acceptance and uptake (Norms, NO). This perspective is supported by research highlighting the importance of tailored communication strategies in promoting new technologies [89,113]. Conversely, some researchers argue that overemphasis on consultation if not done properly can delay implementation and dilute the effectiveness of interventions [114]. Therefore, striking a balance between community consultation and efficient implementation is key for successful solar PV adoption.

The discourse surrounding the adoption of solar energy technologies in rural Zambia emphasizes the crucial roles of observational learning and peer influence in information dissemination. Observing peers benefiting from new technologies significantly shapes individuals' decisions to adopt similar innovations, as evidenced by the rapid acceptance of mobile phones, solar chargers, solar lighting, solar torches and piped water in rural communities. Moreover, community participation and ownership are essential for sustaining these technologies, as projects often fail without local engagement. Additionally, addressing psychological barriers to change and fostering a mindset transformation are vital for enhancing community members' perceptions of their ability to engage in development initiatives. Moreover, there is a need for balanced approaches that integrate external support from government and aid agencies with community involvement. There should be emphasis on effective information dissemination to facilitate technology uptake, aligning with the broader themes of social influence in technology adoption.

8. Recommendations

Based on the findings and conclusions of this study, the following recommendations provide a systematic and logical framework for fostering the sustainable adoption of solar photovoltaic (PV) technology in rural Zambia. These recommendations aim to address barriers, promote community empowerment, and contribute to sustainable poverty alleviation. By implementing these recommendations, it is posited that the Zambian government can create an enabling environment for the sustainable adoption of solar PV technology in rural areas. The strategic integration of peer influence, community participation, mindset transformation, policy support, tailored solutions, and financial models will address the unique challenges faced by rural communities, ensuring that solar PV systems contribute to poverty alleviation and community empowerment.

8.1. Leverage peer influence for technology uptake

To facilitate the adoption of solar PV technology, the government, in collaboration with aid organizations and development banks, should harness the power of peer influence and observational learning. Peer-led demonstrations, conducted by local champions who have successfully adopted solar technologies, can showcase the tangible benefits of these systems and build trust within communities. The Ministry of Energy and the Rural Electrification Authority (REA) should play a key role in supporting these efforts by improving accessibility and infrastructure in rural areas. Leveraging peer influence in this way will increase the visibility and credibility of solar technology, encouraging its wider adoption.

8.2. Foster Community ownership and participation through strengthened governance structures

Community ownership and participation are vital for the sustainability of solar PV initiatives. Local governance structures, such as Ward Development Committees (WDCs), should be actively involved in the planning, implementation, and maintenance of solar projects. Strengthening WDCs, as outlined in Zambia's District Integrated Development Plans and supported by the Local Government Act No. 2 of 2019, is crucial for promoting citizen participation. However, WDCs currently face challenges such as insufficient resources, lack of training, poor communication, and political interference. To address these limitations, the government should implement capacity-building programs, improve communication channels, and provide adequate resources to enable WDCs to fulfil their roles effectively. These measures would empower communities to take ownership of solar PV initiatives, fostering accountability and long-term sustainability.

8.3. Integrate mindset transformation into development programs

Mindset transformation is critical to overcoming psychological barriers, such as entrenched poverty mindsets and dependency on external aid. For example, The Ministry of Education and the Ministry of Gender, in partnership with aid agencies like Plan International, should integrate psychological empowerment workshops into solar PV programs. These workshops should focus on fostering self-efficacy and promoting a culture of self-reliance. Coupled with infrastructure support, such initiatives have the capacity to enhance individuals' perceived behavioral control over adopting new technologies, ensuring deeper community engagement and commitment to solar PV adoption.

8.4. Promote policy support for sustainable investments

The Ministry of Finance, in collaboration with donors such as the World Bank, should implement policies that encourage sustainable investments in solar infrastructure. Co-financing models that require partial contributions from communities can empower local populations to take financial ownership of solar PV systems. By prioritizing community-driven investments, the government can reduce dependency on short-term relief while promoting long-term sustainability. Policies that incentivize donor and private-sector partnerships hold the potential to ensure that solar PV systems remain operational and accessible over time.

8.5. Enhance information dissemination and community consultation

The adoption of solar PV technology depends on effective information dissemination and active community consultation. For example, The Ministry of Information and Broadcasting Services, in partnership with organizations like Oxfam, should develop tailored communication strategies that align with local cultural norms and languages. These efforts should educate communities about the benefits, costs, and reliable sources of solar PV products, ensuring informed decision-making. Furthermore, integrating comprehensive consultation processes would help address community-specific needs and preferences, ensuring the relevance and acceptance of solar PV initiatives. Such a participatory approach provides the means to foster trust and enhance the likelihood of widespread adoption.

8.6. Develop financial models for affordable access

The high upfront costs of solar PV systems remain a significant barrier for rural households. To address this issue, the government should promote flexible financial models, such as pay-as-you-go (PAYG) schemes and micro-loans, to enable incremental payments for solar systems. Companies like Fenix International have successfully implemented such models in Zambia, demonstrating their feasibility. By incorporating these approaches into national energy policies, the government would be in a better position to enable access for low-income households to clean and affordable energy, reducing financial constraints as a barrier to adoption.

8.7. Tailor solar solutions to local needs

To ensure meaningful adoption, solar PV solutions must align with the specific energy demands of rural communities. The government should prioritize the development of practical and scalable systems, such as solar-powered water pumps for agriculture and small-scale solar micro-grids for rural clinics and schools. By addressing local needs and integrating solar technology into existing development initiatives, such as agricultural and healthcare programs, the government would have the opportunity to demonstrate the tangible benefits of solar PV technology. This approach will not only improve productivity and social development but also enhance the acceptance and long-term sustainability of solar solutions.

9. Conclusion

Recognizing individual benefits is a powerful motivator for acquiring and financing services within rural communities. The impact of peer observation and social dynamics is evident, as individuals are more likely to adopt beneficial behaviors when they see positive outcomes among their peers. The widespread adoption of mobile phones in rural areas, bypassing landlines, illustrates the preference for user-friendly and convenient technologies. This pattern shows that ease of use and perceived advantages are key drivers of significant technological transitions.

While external aid provides short-term relief, it is not a sustainable long-term solution. Assistance can only be maintained for so long before it becomes impractical, making it essential to develop local solutions rather than relying on continuous external support. The recent reduction of aid to many countries under the Trump administration highlights the risks of dependency and should serve as a wake-up call for nations and communities heavily reliant on foreign assistance. Achieving sustainable development requires self-sufficiency and proactive problem-solving at the local level. Historically, reliance on outside support has created dependency, with policymakers and aid agencies often failing to establish lasting maintenance mechanisms. Promoting community ownership of projects instills responsibility, encourages self-reliance, and helps preserve dignity. Additionally, effective marketing and clear communication are essential for the widespread adoption of solar PV. Ensuring access to reliable information and involving communities in decision-making significantly enhance adoption rates.

A lack of thorough research and potential biases can compromise the validity of findings, highlighting the need for rigorous and objective research methodologies. Strengthening project sustainability and achieving long-term progress require a comprehensive approach—one that emphasizes individual benefits, encourages donor-driven research on the complexities of poverty, and promotes shifts in community mindsets toward independence. As a contribution to knowledge, we developed the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM), an innovative framework that integrates three key theoretical perspectives to provide a comprehensive understanding of the factors influencing renewable energy adoption in rural areas. This model accounts for the interconnected effects of individual perceptions, social influences, and community engagement in shaping adoption behaviors. By offering insights into the complexities of solar PV adoption, RUDSHAM serves as a valuable tool for policymakers, researchers, and practitioners working to develop effective strategies for sustainable energy transitions in rural communities.

9.1. Limitations of the study and recommendations for future research

- ***Study Duration:*** The six-month study period, from October 2022 to March 2023, provided valuable insights but limited the ability to observe long-term adoption patterns, seasonal influences, and system durability in rural communities. Extending the study duration in future research would allow for a more comprehensive understanding of these dynamics.
- ***Geographic Scope and Funding:*** Due to funding constraints, the research was limited to three rural areas in Zambia, reducing the geographic and cultural diversity of the sample. Future studies could benefit from broader funding to include additional regions, enabling more generalizable findings for rural sub-Saharan Africa.

Declaration statement

RESEARCH METHODOLOGY: RESEARCH STRATEGY AND DATA COLLECTION METHODS.

The data collected aims to inform an understanding of social influence on solar PV adoption in rural Zambia by examining various aspects of community dynamics and individual perceptions. Through in-depth interviews and focus group discussions, researchers explored perceived ease of use, perceived usefulness, social norms, and economic factors. By analyzing these dimensions, the study revealed how observing peers, learning from community leaders, and understanding financial models and policy supports shape individuals' decisions. This comprehensive approach highlights the role of social learning and peer influence in facilitating the acceptance and uptake of solar PV systems, providing insights for targeted interventions.

A methodology based on the ten attributes of the Rural Development Stakeholder Hybrid Adoption Model (RUDSHAM) theory provided a detailed understanding of social influence on solar PV uptake in rural Zambia. Each attribute of the RUDSHAM theory contributed to revealing the social dynamics and factors affecting solar PV adoption.

1. Perceived Ease (PE): Researchers collected data on the ease of installation, use, and maintenance of solar PV systems. By analyzing responses from community members, they understood how user-friendly the technology was perceived to be and identified any barriers related to technological complexity that impacted adoption.
2. Perceived Usefulness (PU): The research team assessed the perceived benefits of solar PV systems, such as reliability and energy security, by gathering community feedback. This helped them understand how the practical advantages of solar PV influenced community acceptance and trust in the technology.
3. Norms (NO): By examining social and household norms, as well as the opinions and experiences of influential community members, researchers uncovered the significant role of social learning and peer influence. This analysis identified key opinion leaders who had the potential to promote solar PV adoption within their communities.
4. Perceived Behavior Control (PBC): Data on perceptions of control over the purchase and usage of solar PV systems, including the availability of warranties and configuration options, were gathered. This provided insights into how perceived autonomy and control affected decision-making processes regarding solar PV adoption.
5. Policy Support (PS): Researchers evaluated the impact of government incentives, subsidies, and supplier support on solar PV adoption. This examination illustrated how external facilitation and effective communication of policies influenced community adoption rates.
6. Economic Cost (EC): By analyzing the economic cost of solar PV systems and its impact on household budgets, the research team understood how financial considerations played a crucial role in the decision to adopt solar PV technology.
7. Community Participation (CoP): The level of community involvement in the design, financing, and maintenance of solar PV systems was assessed. This highlighted the importance of collective action and ownership in sustaining the adoption of solar PV technology.
8. Prior Preferences and Practice (PP): Researchers investigated existing energy practices, preferences, and key uses of energy within the community. Understanding these factors provided a baseline against which the potential shift to solar PV could be measured.
9. Green Concern (GC): Data on environmental concern and awareness at the individual, household, and community levels were collected. This helped researchers gauge the extent to which environmental motivations influenced the decision to adopt solar PV.
10. Financial Models of Relevance (FMR): The research team compared current finance practices with other relevant solar PV financial models globally. This comparison highlighted the applicability and potential impact of different financial approaches on solar PV adoption in rural Zambia.

By integrating data from these ten attributes, the RUDSHAM-based methodology offered a comprehensive understanding of how social norms, perceived benefits, economic considerations, policy frameworks, and community involvement collectively influenced the adoption of solar PV systems in rural Zambia. This approach enabled stakeholders to design targeted interventions that leveraged social influence to promote sustainable energy solutions.

The research was conducted over 6 months (October 2022 to March 2023) across 3 remote rural areas in Zambia: Mkushi Rural (Central Province), Kapiri Rural (Central Province), and Chongwe Rural (Lusaka Province). These locations were strategically chosen for their relative isolation and lack of access to the national power grid. A 4-week pre-testing pilot study was conducted with 5 participants in Luano village (Chingola Rural, Copperbelt Province) to ensure the validity and reliability of the research instruments. One research assistant, fluent in English and several local languages (Bemba, Tonga, Soli, Lamba, and Nyanja), facilitated data collection. The primary investigator is also fluent in English and has a working knowledge of Bemba, Nyanja and Lamba.

The data collection involved in-depth interviews, ranging in duration from 30 min to 60 min, with 39 rural farmers, 16 commercial farmers, and 3 key stakeholders from solar energy companies and government policymakers. Additionally, 7 focus group discussions (FGDs), each comprising 8 participants from the selected rural areas (3 from Kapiri, 2 from Mkushi and 2 from Chongwe), were conducted to capture a range of opinions and views from the communities. To address gender sensitivity and dominance issues in FGDs, sessions were facilitated by village headmen or councillors, taking advantage of their trusted positions within the community. Mixed and separate discussions ensured diverse perspectives from both men and women, with participants receiving refreshments and tokens of appreciation.

Recorded interviews and photographs, taken with consent, were securely stored on the University's OneDrive cloud account with restricted access to ensure data security. Data analysis involved coding interview transcripts, using NVIVO 14, into specific themes and extracting relevant quotes to supplement structured interview data. A pilot study interview was conducted resulting in minor adjustments to the protocol based on the pilot results. This multifaceted qualitative approach, including in-depth interviews, FGDs, photovoice, and observations, ensured the validity and reliability of findings by representing various stakeholder viewpoints.

Ethical approval and informed consent protocols were strictly adhered to, ensuring the study's compliance with ethical standards. By integrating the RUDSHAM framework with rigorous research methods, the study provides valuable insights for policymakers, researchers, and practitioners focused on promoting sustainable energy transitions in Zambia and other developing countries.

CRediT authorship contribution statement

Hillary Chanda: Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Eugene Mohareb:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Michael Peters:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Chris Harty:** Writing – review & editing, Funding acquisition, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2025.103972.

Data availability

Data will be made available on request.

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