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Perceptions of Solar Photovoltaic System Adopters in Sub-Saharan Africa: A Case of Adopters in Ntchisi, Malawi

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Abstract: The study reported in this article aimed to deepen the understanding of the mechanisms driving the adoption and usage of solar photovoltaic (PV) systems in rural Malawian households, particularly among communities that have not received prior solar energy interventions. It used a qualitative approach to investigate the experiences of solar PV system adopters in Ntchisi, Malawi. The study included fourteen participants, and data were collected through observations and interviews, which were then analysed using thematic analysis procedures. The study's findings indicate that many individuals in rural areas have installed solar PV systems that lack adequate training, resulting in potentially hazardous installations. The installation of solar PV systems in villages is motivated by several factors, including the lack of electricity, convenience, benefits, and personal interest in learning more about solar systems. The participants have highlighted numerous benefits of using solar energy, such as reduced costs, increased convenience, improved productivity, reliable energy access, and telecommunication services. However, solar PV systems are primarily limited to household lighting, phone charging, and powering televisions and radios; however, not for cooking purposes. The findings imply that governments in sub-Saharan Africa should provide training and guidance on the safe and effective use of solar PV systems, invest more in solar PV infrastructure to enable larger solar systems for cooking, refrigeration, and irrigation, and promote the use of solar energy through education and awareness campaigns to encourage greater adoption of solar energy.

Keywords: solar photovoltaic (PV) systems; motivation; adoption; rural areas

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1. Introduction

Malawi, a country in Southern Africa that borders Mozambique to the south, Zambia to the west, and Tanzania to the north, faces severe challenges in accessing grid electricity. Malawi has the lowest electricity consumption in the South African Development Community (SADC), and is ranked fourth globally in the least access to grid electricity [1,2]. Most of Malawi's grid electricity is generated through hydro, accounting for 80.2% of the installed generation capacity [3]. However, only 5.3% of the 85% of Malawians living in rural areas have access to the grid, representing over fifteen million people without grid electricity access [4,5]. This skewed access to electricity is a significant barrier to economic empowerment and poverty eradication in one of the least developed countries in the world.

The United Nations (UN) recognises that providing electricity access is a vital ingredient in the strategy towards sustainable development, as articulated in the UN's Sustainable Development Goal 7, which calls for member states to "ensure access to affordable, reliable, sustainable and modern energy for all" [6]. However, according to the World Health Organization (WHO), approximately three billion people have no access to modern energy and

rely on wood, coal, charcoal, or animal waste for cooking, lighting, and space heating [6]. This reliance on traditional fuels contributes to environmental degradation and poor health.

Several studies have linked deforestation in sub-Saharan Africa (SSA) to the continued use of firewood and charcoal, particularly for cooking, which increases the rate of deforestation and forest degradation in the region [2,5,7,8]. With one of the lowest levels of access to clean cooking at 1%, Malawi has one of the highest deforestation rates in SSA, estimated at 2.8% per year [1,9]. The increased deforestation presents severe challenges in Malawi, such as the need to travel long distances to fetch firewood and the loss of soil protection, resulting in increased erosion and flooding.

The adverse health effects of using traditional fuels for cooking are also concerning. These fuels burn inefficiently, releasing carbon monoxide and fine particulate matter that contribute to cardiorespiratory, paediatric, and maternal health problems [10]. Indoor pollution is prevalent in rural Malawi, where most households use firewood or charcoal for cooking, candles, and kerosene lamps for light [10,11]. A quantitative study [8] of 20 participants in a rural village in South Malawi found that firewood and charcoal cooking exposed villagers to fine particulate matter ($PM_{2.5}$) greater than 1000 $\mu g/m^3$, which is a hundred times higher than the WHO recommended limit of 10 $\mu g/m^3$. Given such findings, it is unsurprising that air pollution caused an estimated 12,400 deaths in Malawi in 2019 [8].

To address the challenges posed by traditional cooking methods and indoor pollution, there have been several global interventions to minimise indoor pollution and reduce dependence on biomass and fossil fuels. One such intervention was the UN's 10-year-long Millennium Villages Project (MVP), implemented to assist rural villages in ten SSA countries, including Malawi, to achieve the Millennium Development Goals (MDGs) [12]. The project recognised that inefficient and unsustainable energy practices were obstacles to achieving the MDGs, particularly in Malawi, where most rural households use fuel-inefficient three-stone open fires to cook. Some homes supplement three-stone open-fire cooking with an equally inefficient charcoal-burning cookstove called *mbaula*. A more efficient charcoal-burning stove, the *Chitetezo mbaula*, has been developed and reported to have a 50% reduction in fuel consumption compared to conventional *mbaula*. Figure 1 illustrates the common cooking methods in Malawi, starting with three-stone open-fire cooking, a traditional *mbaula*, and the more efficient *Chitetezo mbaula*.

Despite several efforts, there has been little success in shifting from biomass-fuel-based cooking to completely biomass-free cooking, and providing clean lighting in rural areas in Malawi. Some attempts have been made to integrate thermoelectric panels into cookstoves to generate electricity, but these have been ineffective due to the low power produced. Solar home systems (SHS) were introduced in Malawi as part of the MVP initiative, but the high cost of SHS (USD 250 per unit) has limited their adoption beyond donor-funded initiatives. Solar lanterns have had a better uptake due to their lower price, but the adoption of solar energy for cooking and lighting remains low. This study examines the utilisation of solar energy technologies in rural Malawian households, specifically among communities that have not received prior solar energy interventions. The study focuses on the perceptions and experiences of individuals who have adopted solar PV systems around the Malomo Trading Centre in Ntchisi District, Malawi. The insights gained from these communities are vital in deepening understandings of the underlying mechanisms that promote the widespread use of solar PV in Malawi, independent of government initiatives. This study is crucial in identifying the barriers that restrict the uptake of solar technology and informing policy formulation of effective strategies to encourage its adoption. By analysing the experiences of these communities, the study will contribute to the growing body of knowledge on the practical implementation of sustainable energy solutions in developing countries.

(**a**) Three -stone open fire cooking

(**b**) Conventional *mbaula*

(**c**) Conventional *Chitetezo mbaula*

Figure 1. Various biomass cookstoves commonly used in Malawi.

2. Theoretical Framework

The literature has put forth several models for examining the factors influencing the adoption of recent technologies, such as the theory of planned behaviour, the theory of reasoned action, and the technology acceptance model. The technology acceptance model (TAM) is derived from the psychological theories of reasoned action and planned behaviour, and is commonly employed to identify the key drivers of technology acceptance that apply to a wide range of innovative technologies. This research is anchored on the

technology acceptance model (TAM) as the theoretical foundation. According to the TAM, an individual's intention to adopt recent technology is influenced by two main factors: perceived usefulness (PU) and perceived ease of use (PEOU). PU refers to the extent to which an individual believes the recent technology will improve their productivity or quality of life.

In contrast, PEOU refers to the extent to which an individual believes the recent technology is easy to use. TAM suggests that PU and PEOU influence users' attitudes toward the technology, which, in turn, determine their intention to use it. Users are more likely to adopt a technology when they perceive it as useful and easy to use. TAM has been widely used to explain and predict the adoption of various technologies, including information systems, mobile apps, e-commerce, and social media.

Other factors that could be incorporated into this theoretical framework include socio-economic, cultural, and environmental factors. For example, socio-economic factors, such as income and education, could influence affordability and willingness to pay for a solar home system. Cultural factors, such as attitudes towards recent technology and gender roles, could also play a role in adopting solar home systems. Finally, environmental factors, such as the availability of sunlight and the local climate, could affect the suitability and effectiveness of solar energy as a source of electricity.

Overall, TAM provides a useful theoretical framework for studying the adoption of SHS in rural areas in SSA by considering both PU and PEOU and a range of other factors that may influence adoption. In the context of adopting SHS in rural areas in SSA, PU could be influenced by factors such as the availability and reliability of grid electricity, the cost of traditional energy sources, and the potential economic and health benefits of using solar energy. PEOU could be influenced by factors such as the technical knowledge and expertise required to install and maintain the SHS, the availability of technical support, and the system's user-friendliness.

3. Methods and Materials

The study site was chosen because the district has no externally funded solar initiatives and one of the country's lowest grid electricity connections. The survey was conducted in the villages surrounding the Malomo Trading Centre in Ntchisi, Malawi, which has a population of 317,069 people who live in 47,428 households [13]. Only 4.5% of the population has access to grid electricity, and most people rely on firewood and charcoal for cooking and battery-powered torches and LED lights for lighting [14].

This study employed a qualitative approach to collect and analyse data on the experiences of solar PV system adopters in Ntchisi, Malawi. Ethical approval was obtained, and potential participants were identified through a site visit. Only households with externally visible solar technologies were invited to participate, and the authors explained the study's purpose and ethical principles to all potential participants. The study included fourteen participants, from whom qualitative data were collected through observations and interviews. Field notes and pictures were used to document the observations. The interviews were recorded. The audio recordings are transcribed and imported into NVivo for analysis. The theoretical framework was used to develop a priori codes. The authors used thematic analysis procedures to analyse the data, developing initial descriptive codes, which were later organised and revised into higher-order codes through pattern matching and diagramming [15].

4. Findings

This section presents findings from observations and thematic analysis. The results are categorised into four themes. The first theme, mostly improvised solar PV systems, emerged from observations as documented in field notes and pictures. This theme is presented first. The other three themes emerged from thematic analysis. These themes are motivations for adoption and perceived and realised usefulness of solar PV, mainly used at home but not for cooking.

4.1. Mostly Improvised Solar PV Systems

The findings show that many participants installed solar PV systems without proper training or guidance, resulting in improvised and potentially unsafe installations. Figure 2 illustrates such systems, including loose wires, makeshift battery stands, and ground-mounted solar panels. The range of solar PV systems varied from small units, capable of powering a limited number of lighting fixtures and charging cell phones, to larger ones that could sustain an array of household appliances like TVs, music systems, fans, and lighting. However, those with larger systems were also found to be using them to power plasma TVs.

Figure 2. Examples of the solar PV systems in the participant households. (**a**) Example one of the solar PV systems shows (A) batteries, (B) MPPT, (C) inverter, (D) loose wires connecting batteries, and (E) radio/music system and cell phone. (**b**) Example two of the solar PV systems shows a television, a fan, and radio/music system. (**c**) Example three of the solar PV systems show a television and radio/music system. (**d**) Example of layout of solar PV system showing (A) solar panels on the ground, (B) satellite TV dish, and (C) loose electric cable.

4.2. Motivations for Adoption

The participants were motivated to install solar systems for several reasons. Some did so because they lived in areas where electricity was scarce or far away, and solar power

was a practical alternative. An example of this is Participant-1. They were motivated by the lack of electricity in their village and the impracticality of getting it from far away. The electricity grid ended at Malomo Trading Centre, almost 2 km from Participant-1′s village.

> We don't have electricity here in the village because it's really scarce. The closest place where you can find it is so far away from us, it's just not practical. One day, I visited my friend, and I couldn't help but notice the solar system he had set up. He was using it to power his radio and light up his house, which was impressive. Seeing that got me interested, and I started thinking about saving money to buy my solar system so I could use it at home too. So, I got a solar system for lighting and charging our phones. (Participant-1)

Some, such as Participant-1 above, saw their friends using solar systems and were interested in the benefits. In contrast, others learned about solar systems from the radio or talking to community members. For example, Participant-2 learned about solar systems from the radio, which talked about the benefits of using solar and how it could improve their lives in the village. The information helped him understand how solar works and what it can do for them.

> We got much information about solar from the radio. They talked about the benefits of using solar and how it could improve our lives here in the village. It was geared towards the villagers, and they were saying that if we start using solar, we could have a much better quality of life than we did in the past. It was beneficial to hear all that information because it gave us a better understanding of how solar works and what it can do for us. (Participant-2)

Some participants could get solar systems through credit. Access to credit made it easier for the villages to buy and install solar PV systems. The cost was a factor for some participants but overall, the convenience and benefits of using solar power were the primary reasons for the installation. Some participants, such as Participant-3, had acquired the necessary skills to build and wire their systems. Participant-3 learned how to make solar systems in school and used that knowledge to purchase and set up solar equipment when they returned home to their village.

> I was fortunate to have learned how to build solar systems during my school days. When I returned home to the village and started farming, I was able to purchase this solar equipment. Using the skills I had acquired, I was able to set up everything. It has been beneficial in providing electricity to my home and powering my devices. (Participant-3)

The participants installed solar systems due to a lack of electricity in their village, the availability of solar systems on credit from SolarCompany (Lilongwe, Malawi), the benefits of solar systems learned from friends, radio broadcasts, and personal interest in learning more about solar energy. Some participants also had previous knowledge and skills in building and setting up solar systems.

4.3. Perceived and Realised Usefulness of Solar PV

The participants in the discussion highlighted the many benefits of solar energy, such as cost savings, convenience, reliability, and increased productivity. The participants also mentioned the potential benefits of solar energy for irrigation, cooking, refrigeration, and mobile charging. For example, Participant-4 expressed a desire for larger solar systems that could be used for cooking and refrigeration.

> We aspire to have larger solar systems that we can utilise for cooking, allowing us to live like our friends in the town who use solar-powered refrigerators. Solar technology will enable us to use TVs in our villages, which was previously impossible. If you have any knowledge of solar or are interested in learning more, please connect us to the larger solar systems available in town. We require better power systems, especially for refrigeration, since we have items in the village

> that need proper cooling. Access to solar cooking would greatly benefit us and even help with solar irrigation, which could ultimately contribute to the country's progress. Although people in our village don't have solar power to use with irrigation pumps, I believe there are other places where solar irrigation systems are available. (Participant-4)

Participant-5 shared this desire. They expressed a desire for better access to solar energy, which is currently limited in their area. They noted that others are already using solar energy for essential purposes such as irrigation, which is more cost-effective than using engines. Furthermore, they have observed that using solar energy for irrigation produces better outcomes than spending a considerable amount of money on fuel that may not yield the expected results.

> Regarding solar energy, we can only express our desires. We wish we had access to the same resources as others, as our current options are limited. Meanwhile, others are utilising solar energy for more important purposes, such as irrigation. They are not spending as much as those using engines, which can be costly for irrigation. For instance, you may spend a considerable amount of money on fuel for irrigation, but the crops may not yield the expected results. Our friends with access to solar energy can easily irrigate their gardens and achieve better outcomes. (Participant-5)

Some participants indicated solar PV increases productivity by enabling businesses to open after dark. Participant-6 shared how they use solar power to keep their business open for longer hours. This beneficial impact extends to other areas, such as agriculture, as noted by Participant-5, who claimed that those with access to solar energy for irrigation achieve better crop outcomes at a lower cost.

> I use some bulbs in my shop, but I also have a battery that helps me. If I don't charge the battery during the day, I can't use it at night, which means my business can only operate during daylight hours. So, I'm using solar power to keep my business going for longer hours. (Participant-6)

Other participants highlighted the positive impact of solar PV on households. In the past, people used paraffin a lot in lamps for lighting. Participant-2 shared how solar energy has simplified their life by reducing the need for paraffin and allowing for easy phone charging. He introduced a dimension to solar PV usage that is often overlooked: the increased access to telecommunication services, mainly through cell phones, which comes with easy access to charging facilities. This brings with it access to facilities such as mobile banking.

> The demand for paraffin has decreased as people increasingly turn to solar energy. We have also observed this phenomenon first-hand, noticing that paraffin is still available in some rural areas. Still, its usage has significantly reduced due to solar technology. This is precisely why I chose to invest in solar energy, as it simplifies life in many ways. For instance, if I find myself without the K100 ($0.086) required for charging my phone on the road, I can connect to my solar system and charge my phone using solar energy. This simplifies communication and ensures that I am always connected, even here in an area without electricity. (Participant-2)

The participants highlighted issues related to energy independence, reliability, and cost savings associated with off-grid solar. In contrast, the solar system depends on the availability of sunshine, which is more consistent and reliable. As a result, the participants are compelled to continue using their solar system as it provides more consistent and reliable energy.

> I cannot stop using my solar system as I cannot rely on PowerCompany electricity. The power supply from PowerCompany is often unpredictable and frequently goes on and off. On the other hand, the solar system depends on the availability of sunshine, which is more consistent and reliable. As long as there is enough

> exposure to sunlight during the day, I can use my solar system without any issues. Therefore, I am compelled to continue using it as it provides more consistent and reliable energy. (Participant-7)

Other participants added other dimensions to this comparison. Participant-8 pointed out that one of the benefits of solar power is that it becomes individual property once paid off, unlike PowerCompany's infrastructure. They believe this is a reason it would be difficult to stop using solar energy as it provides a sense of ownership and control over their energy source.

> I believe there might be a misconception here. PowerCompany is a government-owned company. Therefore, it's inaccurate to say that you would stop using solar because of PowerCompany. One of the benefits of solar is that it becomes your personal property once you finish paying it off. In contrast, if you have been connected to PowerCompany for 20 years, you still cannot own the power infrastructure. That's why I think it would be difficult to stop using my solar system, as it provides a sense of ownership and control over my energy source. Once we pay it off, it's ours to use as we see fit without the risk of it being repossessed. (Participant-8)

Participant-9 also raised the issue of energy security. They explained that PowerCompany has a lot of power and control over its customers, as they can disconnect them for missing a payment. Once PowerCompany turns off the power, it is difficult to get it back on.

> PowerCompany has its own electricians who are familiar with their electrical system, while there haven't been any issues with SolarCompany. However, the problem lies in the arrangement to monthly service the debt. With SolarCompany, you're all set once you pay off the debt. On the other hand, with PowerCompany, if you miss a payment, they may come and disconnect you, even if they are there for something else. PowerCompany has a lot of power and control over their customers, and once they switch off your power, it isn't easy to get it back on. (Participant-9)

The findings uncover a desire for greater access to solar resources and the potential for solar energy to improve their quality of life and contribute to progress in their country. Three issues were pervasive in the findings: energy independence, reliability, and cost savings. Some participants noted the positive impact of solar energy on households and increasing access to telecommunication services.

4.4. Mostly Used at Home but Not for Cooking

The participants use solar systems for various purposes, such as lighting, charging phones, powering TVs and radios, and shaving. Some participants use solar systems to charge phones for their families and others. For instance, Participant-7 benefits their family by assisting with phone charging, TV, radio, and lighting.

> I use the solar system for powering the TV, radio and charging phones. Mainly, I use it to benefit my family, especially when my brothers don't have money to pay for charging their phones at the shops. I assist them with charging their phones. However, I haven't started charging others as a business yet. (Participant-7)

Participant-4 purchased a solar system on credit to power a plasma TV. Most participants acquired solar PV systems for home use, but a few used them for income generation. Participant-8 and Participant-1 use their systems for business, cell phone charging, and a barber shop business, respectively.

> I use the solar system for lighting, shaving, and charging phones. I also use it to charge other people's phones and my own. (Participant-8)

> I use my solar system for business purposes, primarily for shaving but occasionally for lighting. (Participant-1)

Solar PV system usage was restricted due to the participants' limited knowledge of the subject. In addition, the size of the installed solar PV systems posed a challenge, as it impacted the nature of things that could be replaced, particularly in the case of firewood. Participant-5 suggested that replacing traditional cooking methods is critical to mitigating the negative impact of current practices and preserving the environment.

> We strongly desire to have larger solar systems that enable us to cook and live just like our urban counterparts with access to solar-powered refrigerators. As you can see, nature has been adversely impacted, and the only viable option for preparing food is electric cookers or other electrical means of cooking. By utilising such systems, we can help preserve the environment and reduce deforestation, commonly associated with traditional cooking methods such as firewood. (Participant-5)

The participants highlighted the association between clean and sustainable cooking methods and mitigating the negative impact of traditional methods like firewood. They suggested that replacing these conventional methods is critical for preserving the environment.

5. Discussion

The article reports findings on the experiences and perceptions of solar PV system adopters in Ntchisi, Malawi, highlighting the motivations for adoption, perceived benefits, and issues related to the installations.

The findings suggest that the installation of solar systems in villages is motivated by several factors, including the lack of electricity, convenience, benefits, and personal interest in learning more about solar systems. The study highlights the importance of access to information and credit for promoting the uptake of solar systems in rural areas [16]. The lack of electricity in villages significantly motivates people to install solar systems. In some cases, electricity is scarce, and the nearest electricity grid is far away, making solar power a practical alternative. This finding underscores the importance of providing access to clean energy in areas where electricity is not readily available. Credit availability is another factor that encourages people to install solar systems [17–19]. This finding indicates that financing mechanisms, such as microfinance, can play a vital role in promoting the uptake of solar systems in rural areas. However, the cost of solar systems remains a barrier for some participants, suggesting the need for further research into affordable and accessible financing mechanisms. The study also highlights the importance of access to information in promoting the uptake of solar systems. Participants learned about solar systems through various channels, including friends, radio broadcasts, and personal interest in learning more about solar systems [18]. Different avenues can be used to disseminate information, such as community meetings and workshops, radios and audios, films/videos (using mobile vans or demonstration units), door-to-door campaigns, dramas, and visual posters. These findings underscore the need for awareness-raising campaigns and information dissemination to promote the benefits of solar systems in rural areas. This finding collaborates with an earlier study covering the adoption of solar PV technology in Tanzania and Kenya [20]. Finally, the study shows that some participants had prior knowledge and skills in building and setting up solar systems, indicating the importance of education and training in promoting the uptake of solar systems. This finding suggests that incorporating solar system education into school curriculums could provide valuable skills and knowledge for promoting the uptake of solar systems in rural areas.

In addition, the findings highlight the need for proper training and guidance during the installation of solar systems. The installations by many participants were improvised and potentially unsafe, including loose wires, makeshift battery stands, and ground-mounted solar panels. Improper installation can lead to serious safety concerns, particularly for larger systems, including an inverter that converts low-voltage DC to high-voltage AC. The risk of electrocution is low with 12 or 24 V DC [21], but it is likely

lethal above 120 V DC [22]. An alternating current is considered more dangerous than DC. The order of 240 V, 50 Hz AC employed in appliances sold in Malawi poses a real risk of electrocution if contact is made with exposed wires. This is particularly pertinent for larger solar PV systems sustaining various household appliances like TVs, music systems, fans, and lighting. The risk is reduced for small units capable of powering a limited number of lighting fixtures and charging cell phones. Therefore, it is crucial to ensure that individuals installing solar systems in Malawi receive proper training and guidance to minimise the risks of injury or death. To address this issue, there is a need for training and advice on installing, operating, and maintaining solar PV systems. This could be enacted through community-based training programs, where people can learn from experienced solar technicians.

Furthermore, the findings highlighted both the perceived and realised benefits of solar PV systems. Participants noted several advantages of solar PV energy, including cost savings, convenience, reliability, and increased productivity. This is consistent with other studies that reported benefits of solar PV systems such as in-home cell phone charging [23], longer operating hours for small retail stores [24], increased access to mobile banking [16], and improved quality of life through access media devices such as televisions [25]. Additionally, some participants identified the potential for using solar energy in other areas, such as irrigation, cooking, and refrigeration. Evidence from India, Ethiopia, and Morocco shows that using solar PV in irrigation is possible [24,26]. However, the literature suggests that a small but growing number of SSA farmers use solar technology in agriculture [16,26,27].

The use of solar energy in agriculture is a topic of growing interest, particularly in areas where access to grid electricity is limited. In this study, participants used small single 12 V battery solar PV systems commonly used to power small pumps in Kenya [26]. However, larger systems are needed to irrigate larger farms. For example, a Spanish study found that an optimal size for a pump capable of lifting water through a 40 m head is 300 W/ha for full irrigation and 150 W/ha for deficit irrigation [28]. These requirements exceed the capacity of the solar PV systems used in this study.

Consequently, participants expressed a desire for larger solar PV systems that would enable them to use solar energy as a cost-effective alternative to using engines for irrigation. Access to larger solar PV systems is a crucial challenge in promoting the use of solar energy in agriculture. Evidence from countries with higher adoption rates of solar irrigation suggests that government intervention is necessary. Policies that facilitate investment in solar PV infrastructure in rural areas or provide financing for solar irrigation equipment are needed to realise the potential benefits of solar energy for agricultural purposes. In addition to agriculture, participants in this study also identified a need for larger solar PV systems for cooking and refrigeration. Therefore, promoting larger solar PV systems could have far-reaching benefits for rural communities beyond agriculture. Overall, the findings suggest that, while small solar PV systems are a step towards sustainable energy use in rural areas, larger systems are needed to fully realise the potential benefits of solar energy.

6. Estimated Household Energy Needs

Table 1 shows the estimated electricity usage for a typical village house, if thermal processes are to be discounted:

Table 1. Electricity usage needs per typical village household.

Item	Estimated Wattage
Sound system/radio	20
LED TV (42 in)	50
3 × Lighting bulbs	60 watts (20 watts each)
Phone charging	5

For such requirements as shown in Table 1, one can go for a 150 W solar panel, if a 15% efficiency is assumed, with a battery, inverter, and charge controller. This panel is estimated at 1 m^2. Such a system costs $776 in 2023. For thermal processing, a unit would require about 1.5 kW, and this alone would increase the pricing, hence the reason it has been taken out in the estimation.

7. Implications

There are three main implications of the findings of this study for the Malawi government and other SSA governments. These implications relate to policies surrounding solar PV systems adoption, particularly in rural off-grid areas. Firstly, there is a need for SSA governments to provide training and guidance on the installation, operation, and maintenance of solar PV systems to ensure safe and effective use. For example, governments could work with experienced solar technicians to develop community-based training programs that provide individuals with the skills and knowledge needed to install and maintain solar PV systems. Secondly, there is a need for SSA governments to invest more in solar PV infrastructure in rural areas to enable larger solar systems for cooking, refrigeration, and irrigation. The governments could consider providing incentives to encourage private investment in solar infrastructure, such as tax credits, grants, or low-interest loans. Thirdly, SSA governments could promote the use of solar energy through education and awareness campaigns to help people understand the potential benefits of solar PV systems. This could include highlighting the cost savings, convenience, and increased productivity of using solar energy.

8. Conclusions

This article provides significant insights into the installation and use of solar PV systems in rural areas. It highlights the motivations for adoption, perceived benefits, and challenges related to the installations, including the potential risks associated with improvised and unsafe installations. It also highlights the need for larger solar systems that can be used for cooking, refrigeration, and irrigation. To support the adoption of solar PV systems in rural areas, this article suggests that sub-Saharan African governments' policies should focus on providing training and guidance, investing in solar infrastructure, and promoting the use of solar energy. By addressing these issues, policymakers can ensure the safe and effective adoption of solar PV systems in rural areas and enable larger solar systems for productive use. This study underscores the importance of promoting sustainable energy practices and demonstrates the potential benefits of solar energy for rural communities. Therefore, the findings provide useful information for policymakers, solar technicians, and community members interested in promoting the adoption of solar PV systems in rural areas.

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References

1. IEA; IRENA; UNSD; World Bank; WHO. Tracking SDG 7: The Energy Progress Report. 2022. Available online: https://trackingsdg7.esmap.org/ (accessed on 5 February 2023).
2. Samarakoon, S. The troubled path to ending darkness: Energy injustice encounters in Malawi's off-grid solar market. *Energy Res. Soc. Sci.* **2020**, *69*, 101712. [CrossRef]
3. Taulo, J.; Gondwe, K.; ben Sebitosi, A. Energy supply in Malawi: Options and issues. *J. Energy S. Afr.* **2015**, *26*, 19–32. Available online: http://www.scielo.org.za/scielo.php?script=sci_arttext&pid=S1021-447X2015000200003&lng=en&nrm=iso> (accessed on 5 February 2023). [CrossRef]
4. Eales, A.; Alsop, A.; Frame, D.; Strachan, S.; Galloway, S. Assessing the Market for Solar Photovoltaic (PV) Microgrids in Malawi. *J. Sustain. Res.* **2020**, *2*, e200008. [CrossRef]
5. Eales, A.; Buckland, H.; Frame, D.; Unyolo, B.; Gondwe, C.; Kaunda, M. *Productive Use of Solar PV in Rural Malawi: Feasibility Studies*; University of Strathclyde: Glasgow, UK, 2017.
6. Lee, H.E.; Kim, W.Y.; Kang, H.; Han, K. Still Lacking Reliable Electricity from the Grid, Many Africans Turn to Other Sources. 2022. Available online: https://africaportal.org/wp-content/uploads/2023/06/ad514-pap10-still_lacking_reliable_electricity_from_grid-many_africans_turn__a_lOcRuWQ.pdf (accessed on 5 February 2023).
7. Bakehe, N.P.; Hassan, R. The Effects of Access to Clean Fuels and Technologies for Cooking on Deforestation in Developing Countries. *J. Knowl. Econ.* **2022**. [CrossRef]
8. Saleh, S.; Sambakunsi, H.; Makina, D.; Chinouya, M.; Kumwenda, M.; Chirombo, J.; Semple, S.; Mortimer, K.; Rylance, J. Personal exposures to fine particulate matter and carbon monoxide in relation to cooking activities in rural Malawi. *Wellcome Open Res.* **2022**, *7*, 251. [CrossRef] [PubMed]
9. Jagger, P.; Pedit, J.; Bittner, A.; Hamrick, L.; Phwandapwhanda, T.; Jumbe, C. Fuel efficiency and air pollutant concentrations of wood-burning improved cookstoves in Malawi: Implications for scaling-up cookstove programs. *Energy Sustain. Dev.* **2017**, *41*, 112–120. [CrossRef] [PubMed]
10. Lee, K.K.; Bing, R.; Kiang, J.; Bashir, S.; Spath, N.; Stelzle, D.; Mortimer, K.; Bularga, A.; Doudesis, D.; Joshi, S.S.; et al. Adverse health effects associated with household air pollution: A systematic review, meta-analysis, and burden estimation study. *Lancet Glob. Health* **2020**, *8*, e1427–e1434. [CrossRef] [PubMed]
11. Fullerton, D.G.; Semple, S.; Kalambo, F.; Suseno, A.; Malamba, R.; Henderson, G.; Ayres, J.G.; Gordon, S.B. Biomass fuel use and indoor air pollution in homes in Malawi. *Occup. Environ. Med.* **2009**, *66*, 777–783. [CrossRef] [PubMed]
12. Adkins, E.; Eapen, S.; Kaluwile, F.; Nair, G.; Modi, V. Off-grid energy services for the poor: Introducing LED lighting in the Millennium Villages Project in Malawi. *Energy Policy* **2010**, *38*, 1087–1097. [CrossRef]
13. NSO. 2018 Malawi Population and Housing Census: Households and Living Conditions Report. 2020. Available online: http://www.nsomalawi.mw/images/stories/data_on_line/demography/census_2018/Thematic_Reports/Households%20and%20Living%20Conditions%20Report.pdf (accessed on 5 February 2023).
14. Ntchisi District Council. Ntchisi District Council Socio-Economic Profile 2017–2022. 2020. Available online: https://global-uploads.webflow.com/6061a9d807f5368139d1c52c/610b2a13e394806a5d401805_Ntchisi-District-Council-Socio-Economic-Profile-2017-2022.pdf (accessed on 6 February 2023).
15. Bryman, A. *Social Research Methods (Internatio)*; Oxford University Press: Oxford, UK, 2016.
16. Jacobson, A. Connective Power: Solar Electrification and Social Change in Kenya. *World Dev.* **2007**, *35*, 144–162. [CrossRef]
17. Kizilcec, V.; Parikh, P. Solar Home Systems: A comprehensive literature review for Sub-Saharan Africa. *Energy Sustain. Dev.* **2020**, *58*, 78–89. [CrossRef]
18. Ngonda, T. A scoping review of adopter attributes, motivations, and barriers of solar home systems adoption: Lessons for sub-Saharan Africa. *Renew. Energy Sustain. Dev.* **2022**, *8*, 1. [CrossRef]
19. Wassie, Y.T.; Rannestad, M.M.; Adaramola, M.S. Determinants of household energy choices in rural sub-Saharan Africa: An example from southern Ethiopia. *Energy* **2021**, *221*, 119785. [CrossRef]
20. Ondraczek, J. The sun rises in the east (of Africa): A comparison of the development and status of solar energy markets in Kenya and Tanzania. *Energy Policy* **2013**, *56*, 407–417. [CrossRef]
21. Hankins, M. *Stand-Alone Solar Electric Systems*, 1st ed.; Routledge: London, UK, 2010. [CrossRef]
22. Li, L.; Li, K.-J.; Sun, K.; Liu, Z.; Lee, W.-J. A Comparative Study on Voltage Level Standard for DC Residential Power Systems. *IEEE Trans. Ind. Appl.* **2022**, *58*, 1446–1455. [CrossRef]
23. Stojanovski, O.; Thurber, M.; Wolak, F. Rural energy access through solar home systems: Use patterns and opportunities for improvement. *Energy Sustain. Dev.* **2017**, *37*, 33–50. [CrossRef]
24. Martinot, E.; Chaurey, A.; Lew, D.; Moreira, J.R.; Wamukonya, N. Renewable Energy Markets in Developing Countries. *Annu. Rev. Energy Environ.* **2002**, *27*, 309–348. [CrossRef]
25. GTZ. Financing of Solar Home Systems in Developing Countries. 2001. Available online: https://energypedia.info/images/c/c8/Financing_of_Solar_Home_Systems_in_Developing_Countries.pdf (accessed on 26 February 2023).
26. Lefore, N.; Closas, A.; Schmitter, P. Solar for all: A framework to deliver inclusive and environmentally sustainable solar irrigation for smallholder agriculture. *Energy Policy* **2021**, *154*, 112313. [CrossRef]

27. USAID. Powering Agriculture: An Energy Grand Challenge for Development. 2016. Available online: https://pdf.usaid.gov/pdf_docs/PA00MGB9.pdf (accessed on 26 February 2023).
28. Mohammed Wazed, S.; Hughes, B.R.; O'Connor, D.; Kaiser Calautit, J. A review of sustainable solar irrigation systems for Sub-Saharan Africa. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1206–1225. [CrossRef]