

Solar Energy Challenges for Rural Electrification: Case Study of Lower-Shabelle Region of Somalia

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Abstract

Renewable energy is a promising energy source for sustainability to meet the demands of clean energy in the future and the alternative way of fossil fuels. Somalia has great potential for alternative energy sources, particularly solar and wind power. Apart from that, there are challenges related to the implementation of this alternative energy source especially solar energy for rural electrification in the Lower-Shabelle region in Somalia which can be categorized as social awareness, financial difficulties, and technical obstacles. The aim of this research is to identify and evaluate the challenges of solar energy for rural electrification in Lower-Shabelle region in Somalia, the current energy sources that have been utilized and the possible future strategies that should be in Somalia. This research project is conducted through a survey using an online questionnaire that has been distributed in Afgooye district in Lower-Shabelle region in Somalia. The statistical model of IBM SPSS version 25 was used to study the descriptive analysis of the collected data, reliability analysis and distribution test analysis. Based on the statistical analysis, the results indicated the significance impact of scattered settlement pattern of rural people in this area as 46% of respondents agreed, while 32% participants strongly agreed and 26% agreed towards the impact of traditional way of living of rural people and dependence on conventional energy source. A significant percentage of the respondents have shown strong agreement 39% and agreement of 34% regarding the impact of higher cost of importing off-grid solar products. Additionally, a significant number (46.1%) of them have responded with agreement on low-rate return of from solar projects in the rural areas. Furthermore, respondents recognized the effect of shortage or lack of technical knowledge of solar technologies in this region, with 38% of them in agreement and 36% agreed. Finally, respondents widely agreed about other technical related to solar technologies efficiency like battery overcharge and poor layout of solar panels where most of the respondents agreed about these challenges.

1. Introduction

More than 1.5 billion people around the world still lack access to electricity, and many countries are implementing ambitious and difficult grid connectivity programs using centralized power generation, which is the primary electrification method. About 14% of the world's population does not have access to electricity. About 95% of them live in the sub-Saharan African rural areas. Diesel generators are often the only source of electricity in these

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areas. These diesel generators are expensive to operate [1]. The success of rural electrification programs to date has been limited. Due to the marginalization of the poor and isolation from established grids, an estimated 85% of the world's 1.2 billion people who do not have access to electricity live in rural areas [2]. The challenge is to find an efficient and economically viable way to provide modern energy options in some of the world's most remote and poor areas. In the sub-Saharan African countries, electric grids are only available in urban areas while less than 20% of rural populations in SSA countries has access of electricity [3].

The electrification rate of Somalia is 32.95% [1]. The rural electrification rate is predicted to be 4%, and the urban electrification rate is predicted to be about 33%. Electricity bills are high, ranging from \$ 0.5 to \$ 1.5 / kW [1]. The Somali coastline is about 3300 kilometers long and represents excellent undeveloped wind and solar energy resources. Somalia is one of the African countries with the greatest potential for wind and solar resources. Limited regulations, exclusive distribution controls and poor infrastructure are hampering the development of the renewable energy sector [1].

Photovoltaic technology is the most cost-effective and efficient solution and is widely used to power remote areas in developing countries, especially solar home systems (SHSs) for small energy needs. Compared to grid expansion, off-grid solar systems provide a promising solution for these remote locations by bridging access gaps and reducing costs and connection latency [4]. Rural electrification with solar PV has both social and economic benefits. In terms of social benefits, electricity helps children to learn at night, women to work, and so forth [5], [6]. Although huge money is invested to manage electricity access challenges in sub-Saharan African countries, still most of the rural population in these areas have insufficient power. In the last two decades, sub-Saharan countries have seen some improvement in power access, but it is limited mostly to urban regions. The statistics have shown that the access rate of electricity increased by 9 million per year from 2000 to 2013, while between 2014 and 2019 have reached 20 million people per year [7].

Even though they are cheaper than expanding the electrical grid, there are plenty of obstacles that make the application of solar home systems SHSs a difficult task [8]. One of the main barriers for sub-Saharan African (SSA) electrification practitioners is financial difficulty, as less than 10% of rural sub-Saharan African (SSA) households have access to electricity and the overall access rate is less than 25% [2]. Off-grid solar systems offer a viable way to electrify these rural locations by bridging the access gap and offering lower prices and shorter wait periods till connection than grid expansions. A mini-grid system comprises a power generating and distribution system that supplies energy to isolated loads, which can be supplemented by an energy storage system [4]. Even though off-grid solar has a significant amount of potential to provide in terms of supplying low-carbon power for power generation and the elimination of poverty, its development can be difficult [9]. These challenges of the photovoltaic could be technical, economic, and social as discussed below.

1.1 Technical Challenges

Solar photovoltaic (PV) systems are claimed to be dependable and long-lasting. While the PV module has been tested and confirmed to work, not every part of the system is at the same level of technological proficiency. Batteries may become the weak point in both off-grid and hybrid systems. Overcharging as well as discharging can affect the durability of batteries. Batteries, despite their simplicity, need some repair and protection on a regular basis.

However, in rural regions, where there is a significant degree of lack of knowledge and a lack of experience with today's technology, and with solar in specifically, it is more of the standard than the exception, even the basic technical operations may prove to be complex [10]. According to the findings of research conducted in Africa in compared with the rest of the global, there is indeed a widespread scarcity of material in Africa that is associated to energy [11]. The technical constraints that were highlighted by the interviewees in some of African countries were divided into three main categories which are limited supply of good quality solar panels, operational challenges with delivery, and a lack of skills in management and maintenance [12]. The other technical limitations differ depends on solar energy technology. For example, in the field of photovoltaic (PV), the basic technical challenges occur in low power conversion efficiency of the Photovoltaic panels, quality limitations of components like inverters and batteries, and an insufficient availability of raw materials like silicon for local assembly of the system [13].

1.2 Social Challenges

The implementation of solar systems was significantly impacted by the presence of social constraints. Social barriers can be listed such as inflated expectations about what a solar energy could offer, robbery and vandalism, and inexperience with the technology as being among the most challenges related [14]. Most People in the African rural areas do not have much idea of understanding the concept of the photovoltaic system installations. The rural villages have a fragmented habitation arrangement, which is another factor that limits the progress of PV system in remote areas. It is challenging to distribute the electricity networks because, much as in rural settlements throughout Southern Africa countries [15].

1.3 Economic Challenges

Although off-grid solar systems provide the potential of economic growth, improvements in health and increased access to educational opportunities, there are still other certain financial obstacles in east African countries that need to be tackled. Some of these barriers related to the low capacity and willingness of people to pay, there is a low rate of return in the off-grid solar business, there is manipulation with theft and robberies, high currency fluctuation due to a large influence for imported products, tariff barriers, and long and complex procedures [16]. Due to the small rate of return in solar energy technologies, financial institutions are hesitant to enter the off-grid solar industry as a result; competition in this sector for expanding access to power in rural regions is decreased. In some countries in east Africa such as Rwanda, Kenya and Ethiopia, the return on investment for solar systems is late, and the continuing usage of solar goods cannot be assured [16]. As reviewed by [17], the cost of solar installation in southern African countries is high in rural areas which makes the rural communities to consider diesel-based generation. However, the variability of diesel prices due to Ukraine crisis makes even more expensive the energy prices in Zambia [18].

Another challenge that the off-grid solar industry faces is market manipulation, which can consist of fake goods or pricing that does not match the level of quality offered by the goods. The customer's ability to make better decisions and their level of confidence in the reliability of off-grid solar mini-grids and solar house installations are both significantly impacted when manipulation occurs [18]. One of the most significant challenges that developing countries must overcome to achieve their objective of offering access to energy for the rural population is the requirement of a massive amount of financial capital for the implementation and development off grid systems to off-grid areas. This is, in addition to the technical challenges and safety concerns that are associated with this effort [19].

2. Research Methodology

The purpose of this research is to identify the challenges related to utilizing solar energy in rural areas of the Lower-Shabelle region in Somalia. In this research, it was examined and discussed detailed information about the different challenges of having solar power in rural electrification in the Lower-Shabelle region of Somalia. This study is quantitative analysis using online questionnaires to collect data. The collected data was analysed with statistical software statistical package for the social sciences (SPSS) version 25.0. The research population of this study was 100 that contained variety of categories which can be residents of Afgooye district in Lower-Shabelle region, Target energy company branch staff both management and employees and students. The sampling method of this research was purposive sampling technique, where respondents are selected by researchers based on the judgment and selection of informants also based on their ability to give specific information. This was done by selecting key insiders from management and staff of Target group of energy company branch in Lower-Shabelle-region. The study focused on some of the challenges viewing three main barriers which are social, economic, and technical that surrounding solar energy development for rural electrification in Lower-Shabelle region Somalia.

The questionnaire was designed to gather information from the study participants in this region of Lower-Shabelle, particularly in the Afgoye district. As usual, it begins with a demographic question about the participant's profile. Following by the survey questions related to the challenges of adaptation of solar energy in the rural areas of this region. The questions are categorized into three main sections: social, economic, and technical. Each section contains several variable questions, using a 5-point Likert scale questionnaire type. The rationale behind these questions is to understand the social dynamics within rural communities, familiarity with solar technology, settlement patterns, and traditional ways of living. In the economic section, economic factors such as affordability, willingness, availability of subsidy programs, return on investment, and the initial cost of solar projects play an important role in understanding the financial challenges. On the technical side, identifying and addressing such questions related to the availability of skilled manpower and regulatory standards in rural areas and efficiency-related challenges are essential for optimizing solar energy utilization efficiency in rural areas.

Normality was carried out to the collected data to measure if data is normally distributed. In this study, both methods Kolmogorov-Smirnov analysis and Shapiro-Wilk analysis was used to measure the normality test of the collected data. Sig or P-value is parameter used to determine if the data is statistically significant or not significant meaning that if P-value is less than 0.05 it is statistically significant and there is significant relationship between variables that have been studied. If P-value is greater than 0.05, it is statistically not significant and there is not relationship.

3. Results and Discussion

Total of 100 questionnaire samples were distributed in Afgoye district in Lower-Shabelle region of Somalia. The reliability analysis of this study indicates that this study has an excellent internal consistency of all elements of

the questionnaire as Cronbach's alpha coefficient is 0.907, while the number of responses were 89 out of 100 distributed sample of questions as shown in in table 1.

Table 1 Reliability analysis for all Items

	Cronbach's Alpha value	Distributed Questionnaire	Number of respondents
Real Study	0.907	100	89

Table 2 summarizes the demographic statistics which contain gender, age of the respondents, occupation, and the business type they involved. The distribution of the sample size is almost representative of the general community of the Afgoye district, and an effort was made to present the rural perspective on the challenges associated with utilizing solar energy in this region.

Table 2 Respondents' profiles

	Description	Frequency	Percentage
Gender	Male	74	83%
	Female	15	17%
	Total	89	100%
Age	18-35 years old	72	81%
	35-45 years old	14	16%
	45-55 years old	3	3%
	Above 55 years Old	0	0.0%
	Total	89	100.0
Occupation	Employee	30	34%
	Businessmen	14	16%
	Student	34	38%
	Others	11	12%
	Total	89	100.0%
Type of Business	Technician	15	17%
	Solar provider	15	17%
	Others	59	66%
	Total	89	100.0%

3.1 Descriptive Analysis of Social Challenges

Table 3 shows the questions of social challenges that have been asked to the respondents. The variables (questionnaire statements) and the respective codes have been presented in the table.

Table 3 Variable codes and descriptions of social challenges of solar energy for rural electrification

Variable code	Variable descriptions
SCSRE1	Unfamiliarity with the solar technology among the rural communities.
SCARE2	The scattered settlement pattern of the rural communities in Somalia
SCSRE3	The traditional way of living of rural communities and dependence of conventional energy sources
SCSRE4	Level of domestic users of solar energy technologies is low for rural community.
SCSRE5	Building solar farms may require vast area of land to produce the power required in rural areas
SCSRE6	Insufficient information about environmental and social development benefits of solar energy

Table 4 shows the descriptive statistics of eight variables of social challenges for solar energy in rural electrification in Lower-Shabelle region in Somalia. These variables are the question statements that have been asked in the questionnaire survey. All items in this section have shown the same minimum and maximum value. As shown in the table 4.7, the social challenges of solar energy for rural electrification (SCSRE4) is found that it

has the highest mean of 3.8652 with standard deviation of 0.89759, and SCSRE7 (Inadequate awareness of solar energy technologies) has the lowest mean value of 3.034. This test result indicates that the mean rank is reflecting from moderate to high level of tendency. Based on these statistics from the survey, SCSRE4, SCSRE3, SCSRE5 and SCARE2 are the significant social challenges faced by rural people in this region as none of them fall below 3.6 mean range.

Table 4 Descriptive statistics of the social challenges of solar energy for rural electrification

Codes	N	Minimum	Maximum	Mean	Std. Deviation
SCSRE4	89	1	5	3.8652	1.089109
SCSRE5	89	1	5	3.7753	1.145672
SCSRE8	89	1	5	3.764	1.132219
SCSRE3	89	1	5	3.6629	1.186513
SCSRE1	89	1	5	3.6517	1.067081
SCARE2	89	1	5	3.6503	1.011931
SCSRE6	89	1	5	3.4607	1.0877
SCSRE7	89	1	5	3.034	1.087702

According to Figure 1, the respondents show their opinion about the general agreement towards these variable questions as most of them agreed and strongly agreed. As shown in Figure 1, the variable question of SCSRE4 (Level of domestic users of solar energy technologies is low for rural community) which has the mean of 3.8652, 38.2% of the respondents agreed and 33% strongly agreed. About 46.1% of the respondents for SCSRE2 (The scattered settlement pattern of the rural communities in Somalia) have agreed, while SCSRE3 (The traditional way of living of rural communities) 32% of participants strongly agreed and 26% of them also agreed.

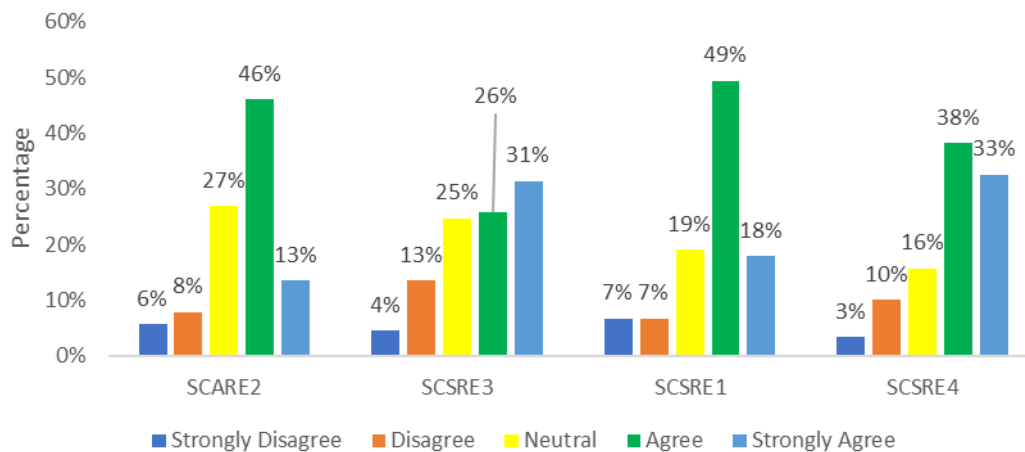


Fig. 1 Social challenges of solar energy for rural electrification in Lower-Shabelle region

3.2 Descriptive Analysis of Economic Challenges

Table 5 contains the variable codes (questions of economic challenges of solar energy) and their descriptions. While Table 6 shows descriptive statistics of these eight variables described as economic challenges of solar energy for rural electrification in Lower-Shabelle region in Somalia.

Table 5 Variable codes and descriptions of economic challenges of solar energy for rural electrification

Variable code	Description
ECSE1	Low ability and low willingness to pay for solar products from rural communities
ECSE2	Lack of subsidy programs from public sector
ECSE3	The massive financial capital required to implement and develop off-grid solar system in rural areas
ECSE4	Few institutions able to train technicians and Engineers
ECSE5	Low rate of return in the solar energy projects

ECSE6	High currency volatility related to the country's economic state
ECSE7	High start-up costs of solar projects in rural areas
ECSE8	The off-grid solar products are imported at high costs

The variables are ranked based on their means with result that indicates ECSE3 (massive financial capital required) recorded the highest mean value of 4.1011 and standard deviation of 1.08758 while ECSE6 (high currency volatility) shows the lowest mean value (M = 3.4607, SD= 1.05589). This table presents the interpretive summary of results indicated by different participants on each variable. The respondent's perception on these challenges of the solar energy for rural areas in this region have an overall of 3.46 to 4.101 mean rank reflecting a moderate to high level of tendency. The table also demonstrates test results for these challenges. The responses perceive significantly greater impact of 'ECSE3 the massive financial capital required to implement solar projects in rural area'; 'ECSE8 Off-grid products of solar system are imported at high costs from abroad'; 'ECSRE1 low ability and low willingness of rural community for solar products'; 'ECSE4 few institutions can train technicians and engineers' and 'ECSE5 Low rate of return from solar projects.

In the percentage wise of respondents after data analysis that have been shown in Figure 2, represents that 45% of respondents strongly agree the impact of the ECSE3 (massive financial capital required to implement and develop off-grid solar system in rural areas), while 35% responded with agree. For the question ECSE8 (off-grid solar products are imported at high costs), 39% and 34% of respondents answered as strongly agree and agree respectively. For the variable ECSRE1 (Low ability and low willingness), 48% and 26% responded as agree and strongly agree respectively, while the variables of ECSRE4 and ECSRE5 49% and 46% of respondents agree respectively as well as 27% and 19% of them strongly agree.

Table 6 Descriptive statistics economic of challenges of solar energy for rural electrification

Code	N	Minimum	Maximum	Mean	Std. Deviation
ECSE3	89	1	5	4.1011	1.08758
ECSE8	89	1	5	3.9775	1.07637
ECSE7	89	1	5	3.8876	0.98209
ECSE1	89	1	5	3.8539	1.01747
ECSE4	89	1	5	3.809	1.1469
ECSE5	89	1	5	3.6966	0.97006
ECSE2	89	1	5	3.6629	1.08653
ECSE6	89	1	5	3.4607	1.05589

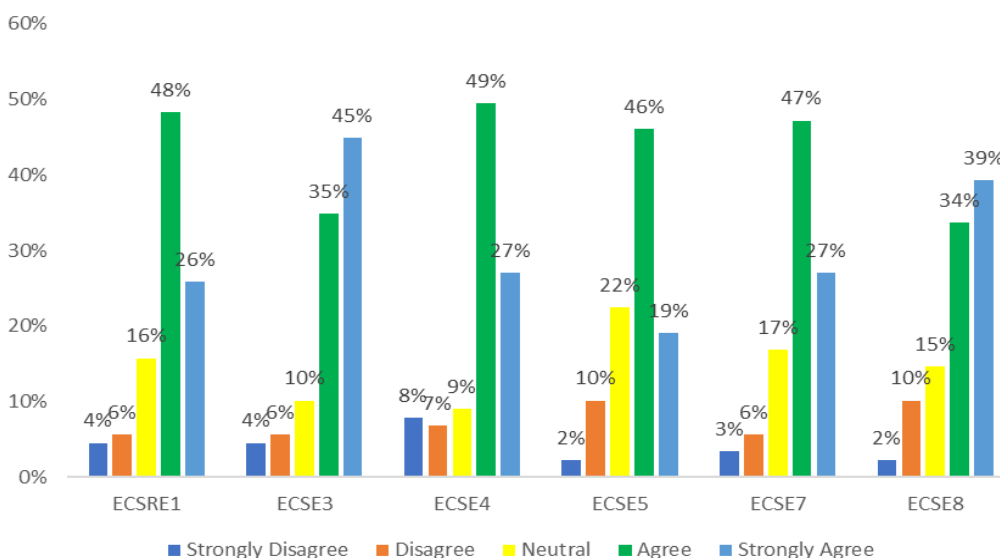


Fig. 2 Economic challenges data

3.3 Descriptive Analysis of Technical Challenges

Table 7 represents the variable code and description of four of technical challenges of solar energy for rural electrification in Lower-Shabelle region in Somalia. The respondents have been asked of their level of agreement towards these variables (questions) as technical challenges of solar energy for rural electrification and descriptive analysis of these variables are presented in Table 8.

Table 7 Variable codes and descriptions of technical challenges of solar energy for rural electrification

Code	Description
TCSRE1	Lack of an appropriate regulatory framework consisting of technical standards for off-grid systems.
TCSRE2	To install any renewable energy technologies, it is required to have technical knowledge and skills
TCSRE3	Shortage of technical trainings for professionals on design and installations of solar system in rural districts
TCSRE4	Technical challenges related to overcharging and discharging batteries and low efficiency of solar panels due poor layout and dust

As variables are ranked based on the mean value, the highest mean value recorded for the technical challenges was 3.955 for TCSRE2 (requirement of technical knowledge) and the lowest one was 3.6629 for the TCSRE1 (Lack of an appropriate regulatory framework consisting of technical standards for off-grid systems). Based on this analysis, the interpretive summary indicates that the tendency of respondent's perception ranges from moderate to high value of mean descriptive analysis in a range between 3.662 to 3.955. The overall range of test results represents the greater impact of TCSRE2 (To install any renewable energy technologies, it is required to have technical knowledge and skills), as well as TCSRE3 (Shortage of technical training for professionals on design and installations of solar system in rural districts), and TCSE4 (Technical challenges related to overcharging and discharging batteries and low efficiency of solar panels due poor layout and dust). TCSRE1 (Lack of an appropriate regulatory framework consisting of technical standards for off-grid systems) shows the lowest mean value of 3.6629 which indicates a moderate level of respondent's perception.

Table 8 Descriptive analysis of the technical challenges of solar energy

Variable codes	N	Minimum	Maximum	Mean	Std. Deviation
TCSRE2	89	1.00	5.00	3.9551	1.04349
TCSRE3	89	1.00	5.00	3.9213	1.11013
TCSRE4	89	1.00	5.00	3.8652	1.07863
TCSRE1	89	1.00	5.00	3.6629	1.23347

Figure 3 shows the percentage of agreement from the respondents while for TCSRE1 most of the respondents agree as 30% both agree and strongly agree, which is more than half of respondents. For the TCSRE2, 37% of respondents agreed and 36% of the respondents also strongly agreed. In TCSRE3, 38% of the respondents agreed while 36% of them also strongly agreed. About 45% of respondents agreed with the impact of TCSE4 (Technical challenges related to overcharging and discharging batteries) and 29.2% strongly agreed. These statistics show the level of agreement towards these challenges as technical barriers to solar energy for rural electrification in the Lower-Shabelle region in Somalia.

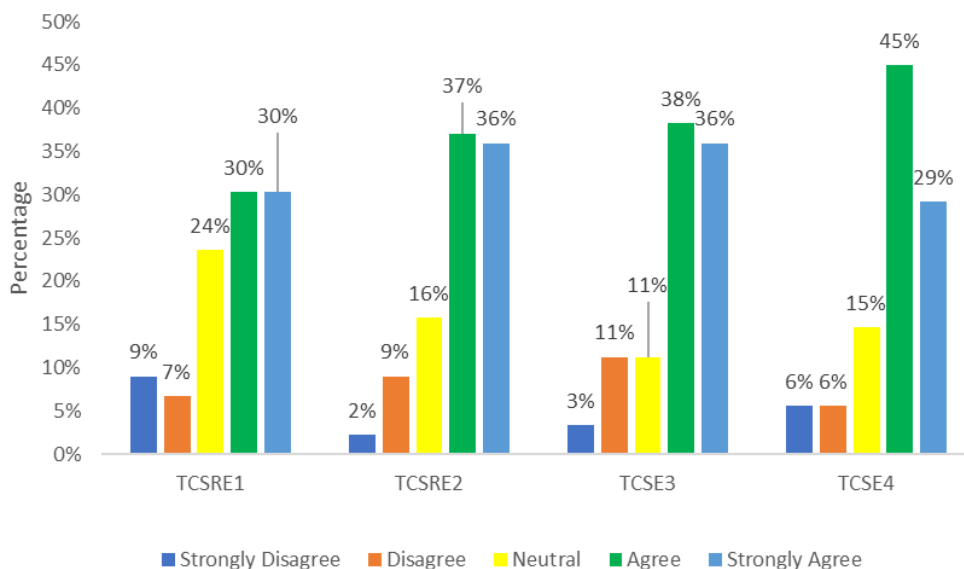


Fig. 3 Technical challenges of solar energy for rural electrification

4. Conclusion

This research work investigated and analyzed the challenges around solar energy utilization for rural electrification in the Lower-Shabelle region in Somalia. The study also examined the current energy sources that most rural people use alongside the future policies that should be developed for Somalia. The questionnaire was constructed based on the objectives of the study. The challenges are classified into three categories: social, economic, and technical. Throughout the study, most respondents agreed to the significant impact of the scattered settlement of rural communities in the Lower-Shabelle region in Somalia, unfamiliarity with solar technology among rural people, the traditional way of living of rural communities, and dependence on conventional energy sources. Most respondents have also shown their agreement about the financial challenges, such as the requirement of massive financial capital to implement solar-based power sources, low ability, and low willingness from local rural residents, in addition to the fact that solar products are imported at high costs. There is a barrier against investment from the private sector, such as a low rate of return from renewable projects in rural areas, and they mostly agree that there are only a few institutions that can train their technicians and a lack of subsidy from the public sector. The study also presented the technical limitations of solar energy. Such barriers include a lack of regulatory frameworks, technical standards, and technical limitations related to battery efficiency, solar panel layout, and dust, where most respondents strongly agree with and strongly agree with these question statements.

The statistical analysis has revealed several critical findings about the challenges of solar energy utilization in this region. About 46% of participants agreed on the impact of scattered settlement of rural people in the region as most Somali population in the rural areas are pastoralists looking for water and pasture. Due to this rural population's dispersed nature, the higher installation cost per unit is less economically efficient than in urban areas. More than half of the participants (58%) strongly agreed and highlighted the consequence of rural communities' traditional way of living and dependence on conventional energy sources. This is due to a need for more understanding and awareness from the rural community towards solar technology, and they are financially unable to shift from conventional sources to off-grid and hybrid energy sources. A substantial percentage of 73%, either those who strongly agreed or agreed, also found the cost of importing off-grid products such as solar panels, batteries, inverters, and other equipment. Nearly half of the respondents have an agreement with the issue of the low rate of return from solar projects in this region. This makes financial institutions and energy companies hesitate to invest in solar energy activities in the rural areas of this region due to uncertainties and risks about the financial returns from their investment. Additionally, a combination of 74% of the participants who strongly agreed and agreed emphasized the impact of a shortage of technical knowledge.

This research highlights some of the challenges of solar energy for rural electrification in the Lower Shabelle region of Somalia. After analyzing and discussing the data collected for this study, we have made the following recommendations. Firstly, based on the social challenges of rural people, there is a need for the development of social awareness for the utilization of renewable energy, especially off-grid solar systems, that should be done to enhance the level of domestic users of solar energy among rural communities. This can be achieved by educating the different types of society, especially the young generation, on the environmental benefits and impact of solar energy on social development.

Secondly, the financial barriers can be effectively addressed through the implementation of financial aid programs, such as subsidy programs. These initiatives are crucial in providing incentives for rural businesses, potentially paving the way for a more sustainable future. There is a promising suggestion for private and public sector investment, recognizing that many rural communities may not have the means to afford the initial capital investment of off-grid solar products. This approach could significantly reduce the constraint of massive financial capital requirements for implementing a reliable energy source from solar energy. Thirdly, it is recommended to focus on technical developments in the areas of implementation, operation, and maintenance. This will help in training more professionals who have the necessary knowledge to handle these technical barriers, further enhancing the feasibility of solar energy utilization in rural areas.

This study has the potential significance of addressing pressing socio-economic and technical challenges regarding solar energy utilization in rural areas in this region. This study investigated and discussed some variable challenges, such as barriers related to the social style of life, economic conditions regarding implementing solar energy projects in this region, and technical obstacles to rural electrification using this alternative technology. Based on these findings, short- and long-term research plans for the utilization of renewable energy for rural areas in this Lower-Shabelle region can be carried out for the broader areas of other renewables, such as wind and solar applications, and further study should be carried out on the techno-economic analysis of hybrid renewable energy sources with diesel generators in the rural areas of this region which could be established on local demand.

Based on the statistical results and tests through IBS SPSS software, the result shows an excellent reliability test with Cronbach's alpha value of 0.908. The results also showed that this study is statistically significant and there is a positive relationship between variables and challenges of solar energy for rural electrification in Lower-Shabelle region in Somalia.

Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** Mohamed Adam Mohamed, Shahrul Azmir Osman, Nurul Fitriah Nasir; **data collection:** Mohamed Adam Mohamed; **analysis and interpretation of results:** Mohamed Adam Mohamed, Nurul Fitriah Nasir; **draft manuscript preparation:** Mohamed Adam Mohamed, Shahrul Azmir Osman, Nurul Fitriah Nasir. All authors reviewed the results and approved the final version of the manuscript.

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