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GEBRESLASSIE, Mulualem Gebregiorgis

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Solar Home Systems in Ethiopia: Sustainability Challenges and Policy Directions

Mulualem G. Gebreslassie☆

Center of Energy, Ethiopian Institute of Technology-Mekelle
Mekelle University, Mekelle, P.O. Box 231, Ethiopia

Abstract

The current energy access in Ethiopia stands at 44%, where 33% is provided through grid connections and 11% through off grid solutions. In order to increase the electricity access, the Ethiopian government has launched National Electrification Program laying out the country's ambition towards universal access by 2025 through a combination of 65% grid-connected and 35% off-grid energy systems such as the solar home systems (SHS). With the government's ambitious plans and increased market diffusion of SHS in the rural communities of Ethiopia, the country requires evidence based comprehensive data on the key challenges of SHS in order to maintain sustainability of the systems. This paper aims to explore the key sustainability challenges associated with the utilization of SHS and provides recommendations to overcome such challenges. This has been achieved through a field questionnaire survey. The study found out that high initial investment cost, lack of local manufacturing, lack of full awareness of the operation, frequent failure of the systems, lack of sufficient maintenance experts, high maintenance and installation costs, lack of spare parts are considered to be the key challenges that are affecting the market diffusion and sustainability of the systems. To overcome these challenges, evidence based policies are recommended.

Keywords: Solar home systems; Sustainability; Challenges; benefits; energy access

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☆Corresponding author. *Email address:* mulualem.gebregiorgis@mu.edu.et (M.G. Gebreslassie)

1. Introduction

Many African countries are currently exploring the use of solar and other renewable energy, with Ethiopia being a strong market for Solar industry and the Government is allowing solar products to enter the country with tax free in order to support the green energy. With this, it is expected that the solar energy market will boom and Ethiopia will have the largest regional power market and also the largest PV market compared to countries in the region. Ethiopia has a rapidly growing economy and offers tremendous opportunities to solar PV suppliers worldwide, having among the strongest solar resources in the world. In particular, the region offers excellent potential for off-grid energy systems with solar PV systems being promoted to replace fuel-based lighting and off-grid electrical needs. Majority of the current installed solar PV systems are being used for telecommunications, health care, elementary and preparatory high schools, household lighting and water pumping for irrigation.

Though there are several success stories on the impact of solar home systems (SHS) to electrify rural settlements, equally there are challenges and many rural electrification programmes using SHS has failed as per the study by [1]. The penetration of SHS also remains low due to what they call a last mile distribution complexity as per the study in central Africa by [2]. A detailed study in Papua New Guinea by [3] showed that there are technical, economic, political and social barriers that affect the diffusion and utilization of SHS. These include substandard equipment, logistical problems, high rates of poverty, lack of financing, poor institutional capacity, unrealistic expectations, unfamiliarity with solar technology etc. A study by [4] indicated that lack of proper cleaning of the solar panels by the users reduces the power output due to accumulation of dust. A study of the use pattern of SHS in south Africa also revealed that it is not only the technical issue that affects performance of the SHS but also the way the users are using such as mounting their panels flat on the ground and the use of their security lights to illuminate their environment and provide security for pole and roof mounted solar panels because of theft [5]. Technical parameters such as wrong system sizing and installation is considered as a major cause of poor performance by a study in Tanzania [6], which leads to lack of viability and sustainability of SHS. These challenges hugely affect the market diffusion, sustainability of the systems, and the public confidence on the technologies.

The current energy access in Ethiopia stands at 44% access rate, where 33% of access is provided through grid connections and 11% through off grid solutions [7]. Ethiopia also has a large gap in electricity access between urban and rural areas and the discrepancy is such that in large towns, 95% of people have electricity (83% in small towns) but dropping sharply to under 10% in rural areas. In order to reduce this gap and fulfill the countries demand, the Ethiopian government has launched National Electrification Program (NEP II) in 2019 laying out the country's ambition towards universal access by 2025 through a combination of grid-connected and off-grid energy systems [7]. With the expected expansion plan, the centralized grid will supply electricity to around 65% of the Ethiopian population and the rest 35% will be off-grid based. Off-grid energy systems such as the solar home systems are believed to be the immediate solutions by the policy makers.

Therefore, with the government's ambitious plans and increased market diffusion of SHS in the rural communities of Ethiopia, the country requires evidence based comprehensive data on the key sustainability challenges of utilization of SHS in order to develop strategies to overcome the challenges and maintain sustainability of the systems. The interaction of communities with the solar home systems include but not limited to: procurement, operation, maintenance which could be affected by financial shortage, lack of local manufacturing, lack of full awareness of the operation, frequent failure of the systems, lack of sufficient maintenance experts, high maintenance and installation costs, lack of spare parts, lack of market diffusion etc. This paper therefore focuses mainly on these soft sides of engineering looking on the sustainability issues originated from the interaction of the communities with the solar home system technologies. Most of the time, studies have been focusing on the technical issues of the technologies such as new technology design, system sizing, efficiency improvement, modeling and simulations etc. However, there is lack of comprehensive study in the African continent that investigates most of the problems related to the interaction and handling of the solar home systems by the communities and providing strategies and policy directions to overcome these challenges.

Therefore, this paper endeavors to comprehensively look and identify the sustainability challenges and provides strategies and policy directions to overcome these challenges in order to improve sustainability of the systems. It specifically seeks to explore knowledge of the public on the maintenance and operation of the system, the public's understanding of the benefits of solar home systems, reliability of the systems, cost, availability of markets, local technology development etc. A combination of these endeavors makes the result of this study novel and strongly believes that this will provide vital information for the wider research community and policy makers. This is critical for facilitating off grid energy access to different sectors.

The paper is structured in different sections with section 2 briefly presents the research questions and hypotheses while section 3 presents the methodology employed in this research work. Section 4 presents results of this research, while section 5 presents the discussions and recommended policies to overcome the challenges. Section 6 presents concluding remarks.

2. Research questions and hypotheses

2.1. Hypotheses

The main purpose of the research project was to contribute to the development of evidence based strategies and polices to overcome different problems in the availability of solar technologies, installation, maintenance and operation of solar home systems, in ways that offer significant development co-benefits for the users. It focuses on technologies for distributed generation (DG)- primarily solar home systems, as these appear to offer the greatest immediate opportunities for improved energy access for a community living beyond the grid systems. There are a number of hypotheses: (i) that the lack of easy availability of the technologies in the market and their high cost hinders diffusion; (ii) that the lack of sufficient installation and maintenance experts is an immediate barrier to sustainable service of these technologies to the community;(iii) that the lack of reliable and frequent malfunctioning of the technologies affects satisfaction of the end users leading to a slow facilitation of energy access; (iv) that the lack of proper and scheduled cleaning of the solar panels affects performance of the system; (v) that the lack of knowledge about the benefits of solar energy technologies can affect diffusion of the technologies to the community; and (vi) that evidence based development of strategies and policies to overcome these challenges can deliver a set of development co-benefits for the community. These hypotheses were tested using the research questions given in the next section and discussions with the users of solar home systems.

2.2. Research problems and questions

This research was initiated to investigate several problems related to solar home systems focusing on the households that are using these technologies. One of the key problems this research focused at was to understand the length of usage and type of technologies being utilized by the communities and the following questions were developed for this purpose:

1. How long have you been using solar energy technology?
2. Which category of solar energy are you using in you house or organisation?

End users of solar home systems often complains on the availability and cost of the technologies and these research problems were investigated with the following research questions:

1. Is it easy to get solar energy technologies in the market?
2. What could be the main reason making the availability of solar energy technologies challenging?
3. What is the cost of full system of solar technology per Watt generating capacity of solar panel?
4. How do you rate the cost of solar energy technologies compared to your economic capacity to buy it?
5. What should be done to make solar energy resources more affordable?

Installation and maintenance experts of solar technologies are understood to be few in the developing world and in order to prove this and other solar home system operation issues, respondents were asked:

1. What are the current hindrances in installing solar energy technology in your house or organisation?
2. At what frequency do you clean your solar panels?
3. How frequently does your solar technology malfunction?
4. What do you do if any of the solar energy components malfunctioned?

Developing countries like Ethiopia have very weak monitoring and evaluation of the quality of imported technologies and investigation of the reliability of the technologies and satisfaction of the communities was critical as part of this research work. In order to understand these research problems, different questions were developed and respondents were asked:

1. How reliable is the solar energy technology?
2. What is your level of satisfaction with the technology you are using or familiar with?
3. How satisfied are you with the length of time that the solar battery lasts?

The use of renewable energy technologies such as solar home systems have significant co-benefits for the communities both economically and environmentally. However, it is not clear if the communities have full knowledge of the benefits of renewable energy and to investigate this, respondents were asked:

1. What are the perceived benefits you get from the renewable energy technologies you have?

2. How important is the issue of global warming compared to other major issues the world is facing today, such as increase in fuel price, food price etc?

These questions were used to test the different hypotheses of this research and provided sufficient information about the research problems under investigation.

3. Methodology

The methodology followed for this study involves review of related literature; establishment and training of teams for collection of the questionnaires from the selected households. The major methodological steps followed during the study are detailed in the subsequent sections.

3.1. Description of the study area

This study was conducted in the Tigray regional state, which is located in the Northern part of Ethiopia. The State of Tigray shares common borders with Eritrea in the north, the State of Afar in the East, the State of Amhara in the South and Southwest, and the Republic of the Sudan in the West. Excluding Mekelle town the state capital, which has seven sub cities, there are six administrative zones: comprising a total of 53 districts and 814 sub-districts. According to the 2016/17 projection of Central Statistics Agency (CSA), the state's population size was 5,247,005 with an estimated area of 54,593 square kilometers. Most (73%) of the population live in rural, while 27% are urban dwellers. About 83% of the populations are farmers.

According a study by [8], Ethiopia has very complex topography leading to highly variable climate conditions. Because of such huge topographic difference, it has a wide range of air temperatures from as low us -7^{o}c in mountainous areas to as high as 50^{o}c in the danakil desert. Despite such huge temperature difference in Ethiopia, a study by [9] on the climatic variability of the Tigray regional state indicated that the air temperature distribution varies with the high lands of Southwest and East having a mean annual temperature of 13.4^{o}c and the Western lowlands about 28^{o}c for the year 2008. Another study showed that average minimum of (20^{o}c) and average maximum of (37^{o}c) was measured in the western Tigray region [10], which is considered the hottest place in the region. According to the National Electrification Programme, majority of the study area has average daily solar irradiation of 5.5 kWh/m^2 per day [7]. Solar systems should be installed at the optimum angle to get the best out of the system but considering Mekelle, the state capital, as a reference the monthly sun height varies with the December month having 52^o while in June the sun height reaches 100^o with the sun height for other months fall in between according to the solar electricity handbook website solar angle calculator. A wind resource assessment study conducted over six cites by [11] shows an average wind speed varying from 3.7 m/s to 6.64 m/s at 10 m above the ground level but according to the global Wind Atlas the wind speed could reach up to 9.75 m/s at 100 m above the ground in some places. As there are few stations measuring the relative humidity in the country, the data is inadequate but with this constraint the relative humidity is believed to be around 60% on the highlands of the country [8]. The summer season is the rainy season of the region covering nearly three months from June to the middle of September [9, 12].

The rated power of most solar panels is measured at standard test conditions with a temperature of 25^oc, which is the optimum temperature where the solar cells absorb sunlight at high efficiency [13]. However, the working range of temperature could be from 15^oc to 35^oc but the efficiency varies with varying temperature and other climatic conditions [14]. The cell temperature of solar panels could even reach 50^oc to 60^oc in tropical areas [13] where the study area is situated though its efficiency drops.

Therefore, considering the climatic condition of the study area and the working range of solar panels, the study area is suitable for the operation of solar panels. This is the main reason that diffusion of solar home systems is increasing in the region and this study focused on households that are using solar home systems, which is a promising technology to facilitate energy access for the communities living beyond the grid system. The geographical distributions of the surveyed households in the regional state are given in Fig. 1.

3.2. Source of data and sample size determinations

In this study, both primary and secondary data sources were used. For gathering primary data, questionnaires and field observations were performed at different zones of the regional state focusing on the country side households. The secondary sources of data included books, published articles, journals and government and non-government documents.

The first step in our research study was to determine a sample size which represents the total households that have solar home systems. The sample size was set considering the required level of precision of the estimates and the resources needed to conduct the survey. Accordingly, the sample size was determined using the formula developed by [15] where, n = required sample size, N = total population size, e = the level of precision (at given confidence interval). This simplified formula is developed with the assumption of simple random sampling

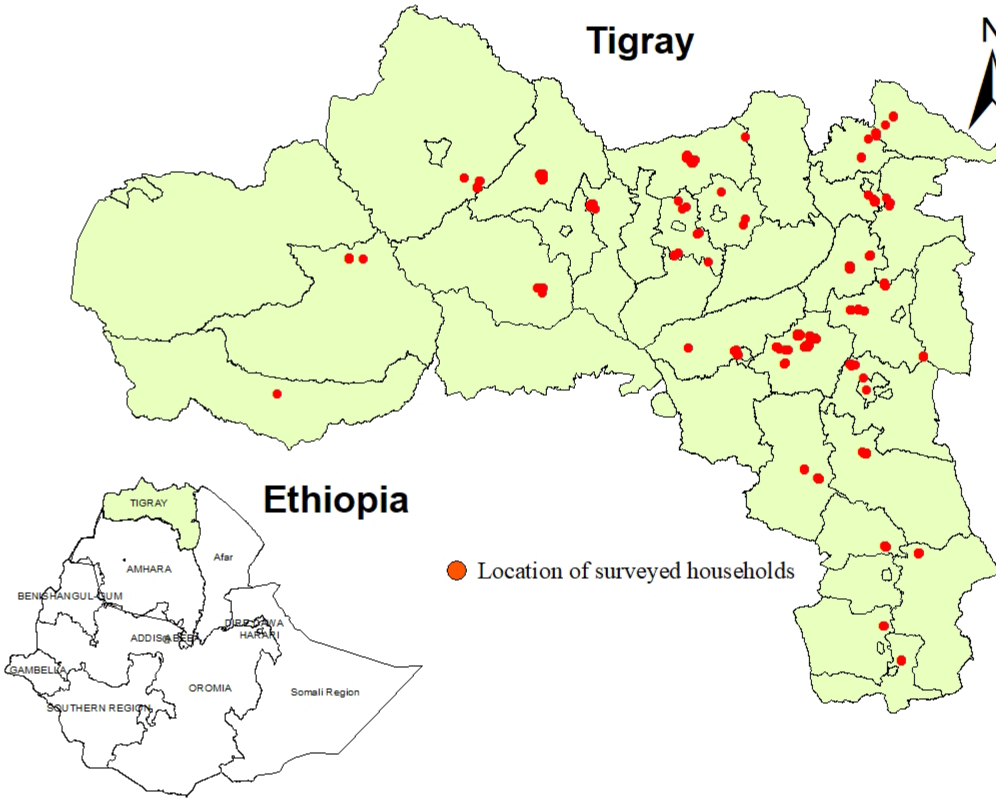

Figure 1: Geographical distribution of surveyed households

design and was considered appropriate sampling method for this research because of the need to analyze the collected data with simple frequencies and percentages.

$$n = \frac{N}{1 + (N * e^2)} \tag{1}$$

Based on the report from Tigray mining and energy agency, there were about 25,586 installed solar home systems in the whole Tigray region during a study on 2019. Hence, based on the formula at 5% level of precision the sample size was estimated at:

$$n = \frac{25,586}{1 + (25,586 * 0.05^2)} = 394 \tag{2}$$

This was proportionately distributed to the different zones of the region based on the number of installed solar home systems and the final rounded sample size was 398 as shown in Table 1.

Name of Zone	# of household	Name of Zone	# of household
Degua Tembien	112	Laelay Maichew	10
Kilte Awlaelo	30	Ganta Afoshum	9
Hintalo Wejerat	25	Enderta	8
Hawzen	25	Glo Mekeda	6
Laelay Adyabo	24	Atsbi	6
Asgede Tsimbla	19	Raya Azebo	5
Welkayt	16	Raya Alamata	4
Mereb Leke	16	Offla	4
Seharti Samre	15	Mekelle	4
Alaje	14	Adwa	4
Kola Tembien	12	Saeseit Tsaedaemba	3
Medebay Zana	12	Erob	3
Tahtay Adyabo	10		

Table 1: zonal distribution of surveyed household

3.3. Survey instruments

The study employed a structured questionnaire to gather the necessary information from the users of solar home systems. This research was part of a large scale project with the questionnaire structured in five sections, with the first part containing the respondents details, the second part containing questions related length of usage and type of technology while third part focusing on availability and cost of the technology. The fourth part contains questions related installation, maintenance and operation of solar home systems while the fifth part focusing on reliability of technology and satisfaction of the communities. The last section of the questionnaire was on the knowledge of communities about the perceived benefits of solar energy. This questionnaire is newly developed based on previous experiences and knowledge of solar home systems in order to test the critical research hypotheses. The questionnaire was developed using the on-line LimeSurvey tool and the data collection was conducted by visiting and interviewing each household and fed in to the online tool.

3.4. Validation of the questionnaire

The questionnaire was pilot tested by undertaking a pretest to assess the level of understanding of the enumerators and respondents on the clarity of the questions. The enumerators were provided full training on how to ask the respondents and collect data and they were given the chance to test their understanding by collecting data from selected respondents. The collected data was analyzed and discussed with the enumerators about the critical issues faced during the interviewing and the respondents understanding of the questions. Based on the reflections of the enumerators and their opinion on the understanding and response of the respondents and the information needed for the research, the content, logical flow, layout and presentation of the questionnaire were amended. In addition to this, objectives of the research were explained to each respondent including confidentiality issues for any personal data during the data collection and once they agreed and give consent, the data was collected.

The second validation was conducted after all the questionnaires were collected using Kaiser-Meyer-Olkin (KMO) and Cronbatch's Alpha measure for overall sampling adequacy and internal reliability of the data respectively. According to [16], the sample size is suggested to be 100 or larger and recommended the sampling adequacy test using the KMO test method to be greater than 0.6. The test result of the sample size of this study shows a KMO value of 0.786, which indicates that the sample size utilized is adequate. Similarly, reliability of the data was checked using Cronbach's Alpha test method and result of the test showed a value of 0.780. An alpha value of 0.7 or above is considered good thus the data used in this study is reliable and valid [17].

3.5. Data analysis procedures

The responses obtained from the different survey participants were feed-in to the on-line LimeSurvey tool and the data was automatically analysed on-line within the LimeSurvey tool. The analysed data in the form of percentages and frequencies were exported to Microsoft Excel. The data was then manually edited, summarized and rearranged according to the obtained responses. After having done such process it was converted to percentages that finally led to data interpretation and description of the entire problem using tables and graphs.

4. Results

The results presented in this section are characteristics of the surveyed households, energy consumption, public awareness and interest for the utilization of solar homes systems, availability and cost of solar technologies, maintenance and operation and reliability of the systems. Detailed presentation and interpretation of these results are given in the subsequent subsections.

4.1. Characteristics of surveyed households

The study has focused mainly on the rural communities that have solar home systems and the survey result showed (see Table 2) that nearly 97% of the respondents are farmers. Most of the rural houses are made of thatched and sheet metal roofs where the solar panels are mounted but not integrated as shown in Fig. 2. The solar panels are hinged to the roof using angle bar or other similar metals.

Occupation of respondents	Percentage
Farmers	97.0
Government employed	2.5
Employed in private and religious organization	0.5
Importer/distributor/seller	0.0
Self employed	0.0
NGO worker	0.0
Unemployed	0.0

Table 2: Occupation of respondents

Understanding the length of time since the solar home systems are installed by the users is important in order to better get the necessary information about the maintenance issues and other related parameters of the study. According to the results, 41% of the respondents said that their systems has been more than 2 years since it has been installed and started using it and 25.4% of the respondents indicated that it has been between one and two years since they start using it with nearly 6.8% used it for about a year. The rest of the respondents indicated that it has been less than a year since they installed the system as shown in Fig. 3. This shows more than 66% of respondents indicated that it has been more than a year

Figure 2: Mounted solar panels in the thatched and metal roofs of the rural houses [18]

since they installed the technology, which was important for this study to identify and understand the critical challenges the communities are facing with those energy systems. The result also showed that the introduction of solar home systems is relatively new to this area with nearly 41% indicated that it has been more than 2 years since they installed it. However, with the huge awareness creation and increased market availability of the technology, the use of solar home systems is showing fast increase in the last one and half years.

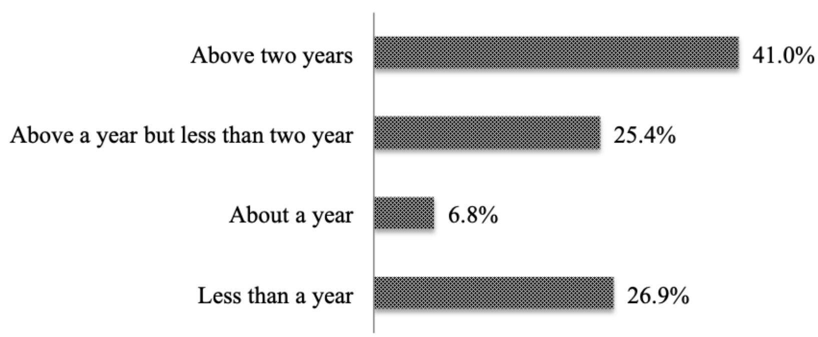

Figure 3: Year of utilization of the SHS

4.2. Energy consumption

The population has been mainly dependent on biomass based energy for cooking and lighting and sometimes they use kerosene based lighting. However, due to the availability of solar based technologies, there is huge expansion of the utilization of these technologies such as lanterns, solar home systems and recently mini-grid systems in the rural areas. The lantern technologies are being used for lighting while the application of solar home systems is mainly for lighting, television, and mobile charging and are installed based on direct current (DC) as most of the applications use low voltage. This study has focused on communities who have installed solar home systems thus the energy consumption by the users could be estimated assuming the hours being used and the installed capacity of the solar panels. However, capacity of the solar panels installed in the study area ranges from 8 Watt (W) to 300 W. There were also institutional solar panels installed in schools and health centers with a capacity of 1.2 kW. This difference makes the energy consumption per household different but the average energy consumption per household could be easily estimated considering the total installed capacity based on the total number of households. The total power of the different size installed solar home systems in the 25,586 households is estimated to be around 1.7 MW according to the regional energy agency. In the rural settings, users are using lighting from around 6 pm to a maximum of 11 pm. They may also use charging once a day for approximately two hours per charging. With these approximation and knowledge of the rated power of the installed solar panels, the total energy generated by the installed solar home systems is estimated to be 11,900 kWh per day. Considering the average daily solar irradiation of 5.5 kWh/m^2 per day of the region [7], the total area needed for the generation of 11,900 kWh energy is around 2164 m^2, but a 20% of this estimated area is normally added to account any losses. According to the 2016/17 projection of Central Statistics Agency (CSA), the average family size in a household is 4.2 and thus the average energy consumption per Capita becomes 40.42 kWh per year, which is way below the 95 kWh per Capita energy consumption of the country based on the information from the Ethiopian Electric Power. The main reason for this lower energy consumption is that all the communities did not use this energy for cooking, which takes the lion share of energy consumption in households.

4.3. Public awareness and interests for the utilization of solar home systems

The government of Ethiopia in collaboration with development partners and private sector is promoting the distribution and installation of solar home systems to the rural communities. However, there is no clear data that shows the public is interested to install solar home systems. As part of this study, the communities were asked what they think of installing solar home systems and the systems associated challenges. Nearly 30.9% of the respondents indicated that they have insufficient knowledge of the technology to maintain and operate while about 25.9% the respondents believe that there are no reliable maintenance experts as shown in Table 3. High maintenance and installation costs are also considered as the key challenges with 18.1% and 17.9% of the respondents respectively. Low reliability, possible fire spread, systems hazards, complex installation process and difficult of use are also considered some of the other challenges with varying degree of the respondents.

Frequency of panel cleaning	Percentage
insufficient knowledge	30.9
No reliable maintenance experts	25.9
High maintenance costs	18.1
High installation costs	17.9
Low reliability	5.0
Possible fire spread	1.1
System hazards	0.5
Complex installation process	0.5
Difficult of use	0.1

Table 3: Key challenges for the utilization of solar home systems

In contrast to the challenges of acquiring the solar home systems, the communities are well aware of the perceived benefits of using solar based renewable energy resources with 29% of the respondents indicated that the systems has the ability to reduce oil dependence with 26.8% of the respondents believe that the utilization of solar home systems can improve life quality of the public. In addition, 23.4% of the respondents indicated that the use of solar energy can bring economic development with 11.5% indicated that it can help in protecting the environment. Communities are also fully aware that the utilization of solar energy can facilitate green development as shown in Fig. 4. This is similar with studies conducted in Saudi Arabia and Nigeria by [19, 20] where majority of the surveyed communities were aware of the benefits related to the utilization of solar home systems and solar PV respectively. A similar study in Texas by [21] also showed that communities have positive attitude towards SHS adoption and utilization.

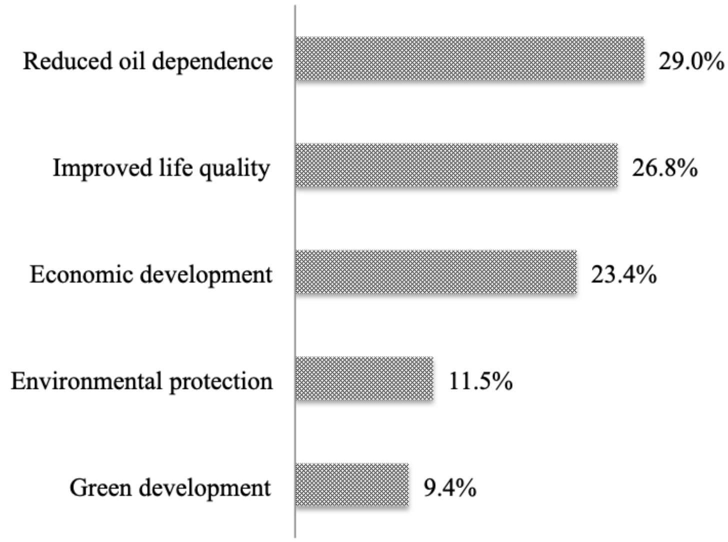

Figure 4: Perceived advantages of solar home systems

4.4. Availability and cost of solar home systems in the market

Availability of the solar home systems with affordable cost is a key factor for facilitating energy access at the rural communities. The communities were asked to identify the key reasons that makes availability of the solar home systems challenging and according to the survey, more than 42% of respondents indicated that there are no solar home system shops with 34% of the respondents indicating that the population is not aware of the advantages. Nearly 23% of respondents said that there is lack of local manufacturing of the technologies with the reset of respondents focused on the lack of purchasing capacity of the communities, no spare parts, and manufacturers are not known as shown in Fig. 5.

However, more than 52% of the respondents are neutral about the affordability of the technology with 15.3% saying that the cost is less affordable while 15.8% said the cost is affordable. A study in Bahrain by [22] complements this fact where the initial investment of residential PV systems is considered a key barrier. However, about 12.6% of the respondents said that the technology is highly affordable as shown in Fig. 6. Though, nearly 28.4% said the cost is affordable or highly affordable, it is clear that most of the respondents are not happy with the existing cost of the technologies. The current market price of solar panels in the region varies based on the capacity but are on average it is around 3370 USD per a kW rated solar panel. This cost appears to be not affordable by substantial number of respondents, which is attributed to their low income level. The electricity Tariff for

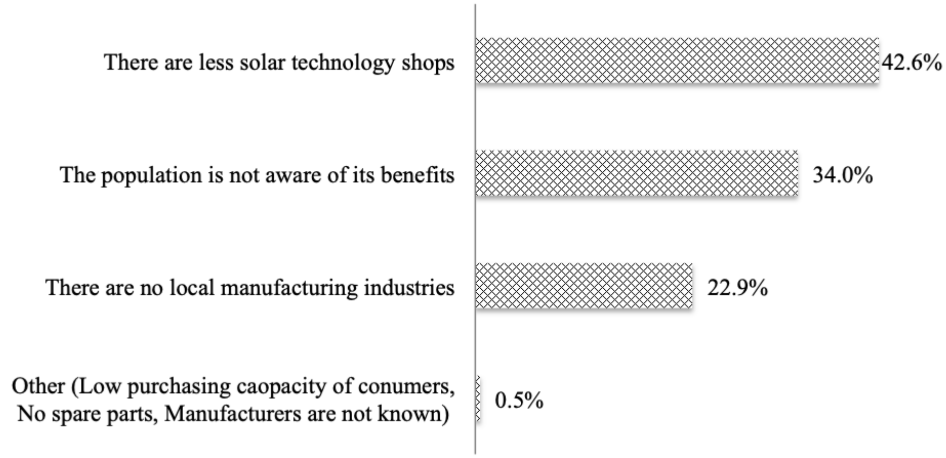

Figure 5: Main reasons making the availability of solar energy technologies challenging

households in Ethiopia is 0.00771 USD for consumption up to 50 kWh and 0.01586 USD for consumption up to 100 kWh, and 0.02999 USD for consumption up to 200 kWh since December 2019 and the increase continues as the consumption increases according the Ethiopian Electric Utility, but it is considered cheaper than the electricity tariffs in neighboring countries. This tariff is for electricity supply from the grid system and most of the rural communities prefer to get access to the grid rather than buying solar home systems because of the high initial cost. However, this is not possible considering the scattered living conditions of the communities and the associated high cost of distribution combined with the low power generation capacity of the country.

A combination of the above challenges are the key bottlenecks for facilitating energy access in the rural communities with only 2.13% of the home in the regional state having solar home systems according to the data obtained in 2019 from the energy agency. The communities were given the opportunity to recommend on different mechanisms that can help to overcome these challenges and facilitate energy access in the rural communities. Based on the survey results, 33.3% of the respondents recommended for the government to provide more subsidy with 27.8% of the respondents recommended on relieving import tax in order to reduce cost of the technologies as shown in Fig. 7.

Investing in infrastructure to strengthen and manufacture solar energy technologies locally is also recommended by 24% of the respondents while 14.8% of the

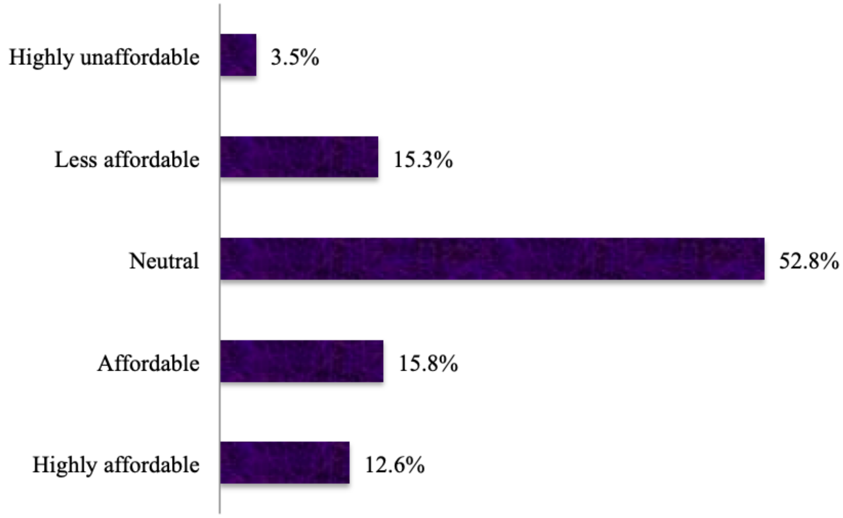

Figure 6: Rate of the cost of solar energy technologies compared to the community's capacity

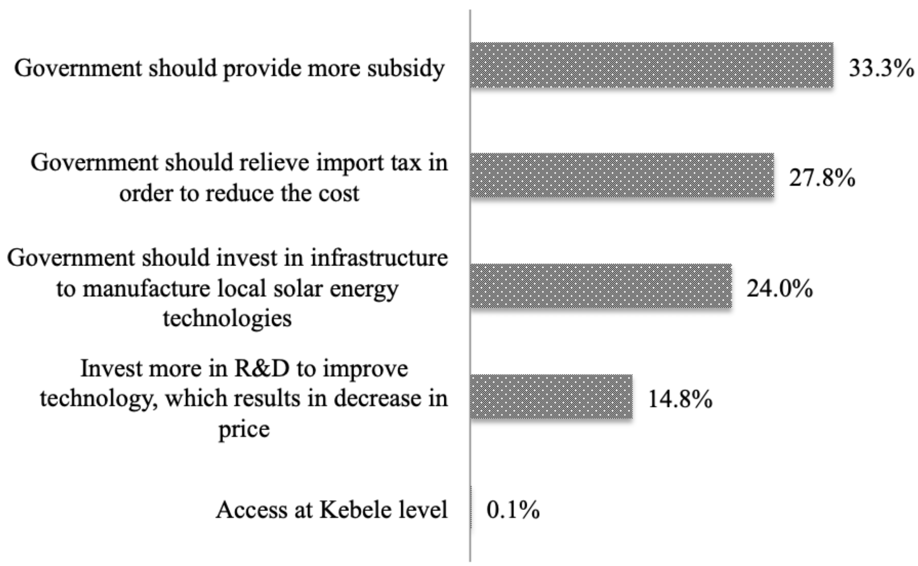

Figure 7: Ways of making solar home systems affordable

respondents recommended for more investment on research and development to improve efficiency of the technologies in order to reduce the cost.

4.5. Maintenance and operation of the solar home systems

The performance of solar energy system depends on the availability of sunlight as well as the variety of the environment [23]. The accumulation of soil on the solar panel surfaces is one of the results of the environmental conditions and blocks the sun's irradiance from reaching to the solar panels leading to power loss [4]. According to a study by [24], fine particles do have more impact on the performance compared to coarser particles. The dust accumulation is commonly called hard shading and it is recommended that the solar panels should be cleaned weekly during dry season and daily for intensive dust accumulation areas according to [4, 25] in order to reduce the power loss. An investigation was conducted to see the awareness and understanding of the communities on the impact of dust accumulation on the performance of the systems and if they follow guidelines to clean the panels but nearly 66.6% of the respondents said they never cleaned their solar panels with only 8% of the respondents cleaning it more than four times a year. The rest of the respondents provided varying frequency as shown in Table **??**. This is contrary to the recommendations and is becoming one of the key reasons for malfunctioning and low efficiency of the system. This also leads to a reduced lifetime of the technology.

Frequency of panel cleaning	Percentage
Never cleaned	66.6
Once a year	9.5
Twice a year	5.5
Three times a year	5.5
Four times a year	4.8
More than four times a year	8.0

Table 4: Frequency of solar panels cleaning

Considering that Ethiopia is one of the regions with high dust intensity according to a study by [26], persistent awareness creation in the communities is essential in order to maintain performance of the systems so that the communities could enjoy sustained electricity access. The awareness creation shall include on the methods of cleaning the solar panels. Manual cleaning and mobile cleaners are the two commonly used methods according [4] but considering that the systems are standalone solar home systems and there are no readily available machinery for mobile cleaners, it is recommended that the communities are given full awareness on how they can regularly clean their solar panels manually. There are also natural cleaning methods such as through rainfall and wind but those are mainly seasonal and are not effective in places where these natural resources are scarce.

Communities that have solar home systems has long been complaining about the difficulty of getting maintenance experts when their technology malfunctions. This issue has been considered as a key issue that should be investigated in order to understand the frequency of malfunctioning of their technologies and who they normally call up on when they need maintenance experts. According to the survey results, majority of the communities (76.4%) said their systems never malfunctioned since they installed the technology but considering nearly 33% of the respondents have used the technology for less than a year, they are yet to experience this problem. However, a substantial number of households (nearly 23.6%) has experienced malfunctioning of their systems from once a year to more than four times a year as shown in Table 5.

Frequency of malfunctioning	Percentage
Never malfunctioned since I installed	76.4
Once a year	10.6
Other	6.5
Twice a year	5.0
Four times a year	1.0
More than four times a year	0.5

Table 5: Frequency of system malfunctioning

These households are experiencing huge sustainability issues coupled with the lack of service centers nearby their homes. This was backed by nearly 49% of the respondents. However, nearly 40.6% of the respondents do have service centers nearby and get maintenance services when their system malfunctioned. There are also lack of maintenance experts in some areas and few of the respondents said they repair it themselves, call the government energy agencies, ask private sectors for help etc. as shown in Fig. 8. Though there is no standard price for maintenance of solar home systems in the region, a recently installed 600 W institutional solar system by the German Agency for International Cooperation

(GIZ) has a contractual service and maintenance cost of nearly 40 USD per year and 68 USD for 1.2 kW capacity solar system. A proportionately calculated service and maintenance cost for the different rated solar systems installed by the households appears to be expensive for the communities that are characterized by low income. These challenges are a key concern of the communities, which is also proved by a study in Malaysia where the general public is worry of the ease of use of Solar PV compared to their advantages [27].

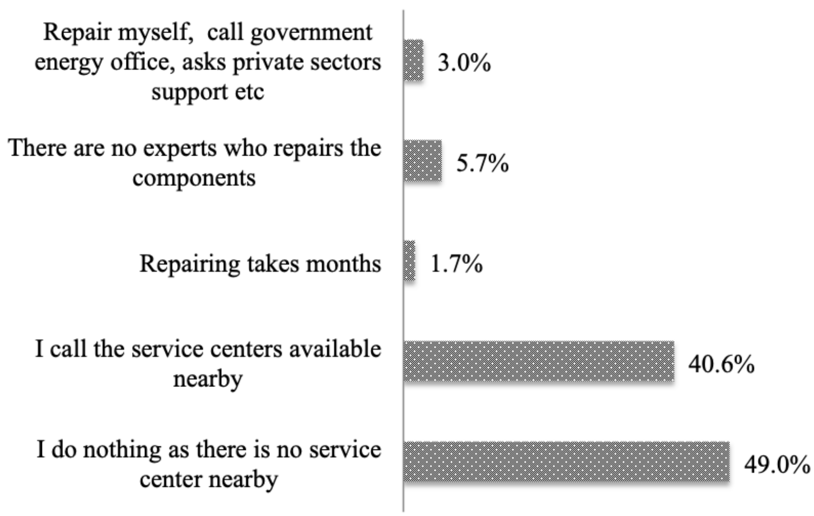

Figure 8: Maintenance of malfunctioning solar home systems

The battery in the solar home systems is one of the key technology components that affect the sustainability of the system and nearly 61.6% of respondents are either satisfied or strongly satisfied with the service period of the battery though the rest are not (See Fig. 9). This means service period of the battery is not satisfactory for low number of the users though this may not give the true extent of the issue considering that majority of the households used the systems for short period of time as shown in Fig. 3.

4.6. Reliability of the solar home systems

High reliability of the solar home systems improves the community's confidence in the technology and provides sustainable supply of electricity. The communities were asked how reliable the technologies are and 18.8% of the respondents said that the technology is highly reliable while 41.7% said the technology is

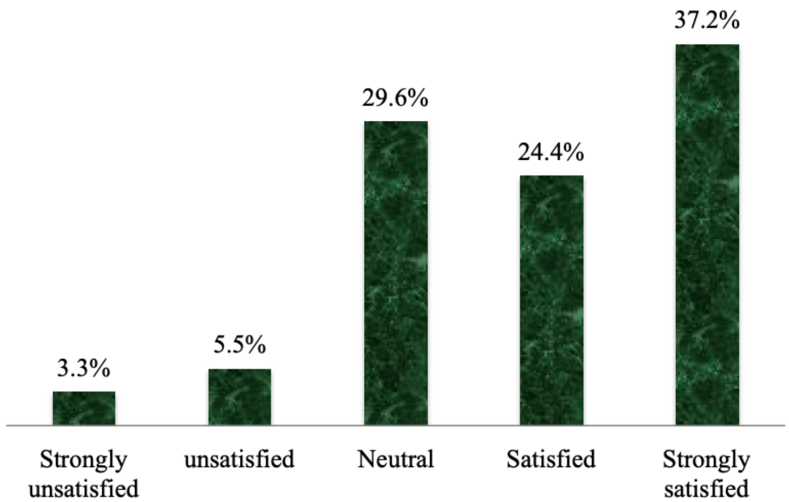

Figure 9: Length of time that a solar battery lasts

reliable. However, 30.7% of respondents indicated that they are neutral about the reliability with the rest of the respondents indicated that the technologies are either unreliable or highly unreliable as shown in Fig. 10.

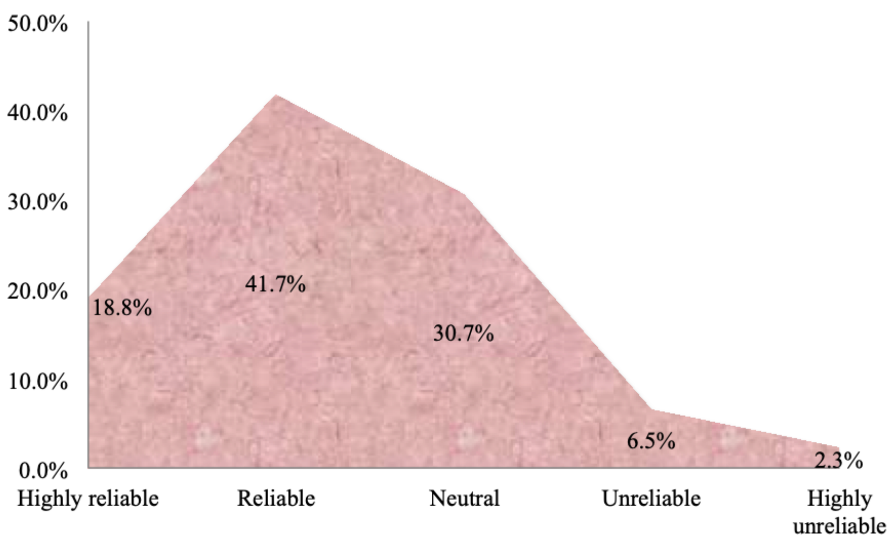

Figure 10: How reliable is the solar energy technology?

5. Discussions and recommended policy directions

The current National Energy Policy was issued in 1994, which was recognised to be the first attempt in the country for a policy document to take into account the wide-ranging concerns of all sectors. The policy objectives focused on a range of key areas that were viewed as important for the transformation of the county's economic and social goals. These consisted of securing reliable and affordable energy services for driving key economic sectors, shifting away from traditional fuels to modern energy services, increasing deployment of indigenous energy resources as a proportion of the energy mix, investing efforts to energy efficiency across the energy system, and incorporating environmental protection in energy production and use. At the time when the policy was developed, it was intended to be dynamic - allowing for revisions to take place from time to time to incorporate new developments in the sector and the wider economy. However, for unknown reason, the policy was never updated. Indeed, much has happened over the past 26 years, in terms of structural and transformational changes at national and international levels and this old policy needs to be quickly updated in order to incorporate the new dynamics.

Nevertheless, the energy policy clearly stipulates the need for gradual transition from traditional energy fuels to modern fuels with due and close attention to ecological and environmental issues during the development of energy projects, which is part of the commitment for green economy. Based on the national electrification plan [7], priority focus is given for potential mini-grid development to those most remote areas. While long-term off-grid areas shall be covered primarily by Government financed initiatives, the Government leaves room for private sector and cooperative financed initiatives in areas designated for mini-grid pre-electrification. The Government intends to establish the framework required to implement these privately led mini-grids.

Despite the efforts of the government and private sectors, there are clearly several challenges of the energy sector. At policy level, there are no known detailed and effective policy tools developed by the government such as incentives in terms of financial and in kind support to stimulate the sector by providing priorities based on the available resources and demand of the rural communities. At the end users side, there are clearly several challenges of the off-grid sector particularly solar home systems as proved by the survey conducted in this study. Some of the key challenges raised by the communities are but not limited to:

- High initial investment cost of the technologies, which is affecting market diffusion to most of the rural communities

- Lack of local manufacturing of the technologies
- Limited number of solar technology shops
- Lack of full awareness of the operation and simple maintenance by the communities
- Frequent failure of the systems
- Lack of sufficient skilled maintenance experts either from government, established cooperatives and private sectors
- High maintenance and installation costs
- Lack of spare parts

A combination of these key challenges is a big reason for concern as they are the bottlenecks for the technology diffusion to the rural communities and maintaining sustainability of electricity supply from the systems.

The key challenges identified through this research work requires huge attention by all stakeholders involved in the the development of standalone and mini-grid systems to facilitate energy access and maintain sustainability of the systems.The huge solar energy resources of the region combined with the availability of different solar based technologies is an opportunity to facilitate energy access if the government develops clear and implementable polices and regulations. There are two types of solar energy technologies that are being implemented worldwide. These technologies are Photovoltaic based where electricity is generated for different applications such as lighting, cooking, television, charging and for any other appliances that utilize electricity, while thermal based solar technologies are used for cooking and other hot water applications. It is obvious that both technologies could be beneficial for the rural communities but considering the current technology development, there is no readily available efficient solar based cooking systems and thus communities are not expected to use solar thermal which was proved during this study. However, Photovoltaic systems are being widely used by the rural communities for lighting, charging and television purposes but these systems are not used for cooking purposes considering its energy intensive nature and the need for more large capacity of solar panels incurring high initial investment for the communities. Therefore, policies and regulations should be developed considering all these conditions and focus on these that provide immediate solutions for the communities such as the Photovoltaic based solar home systems. With this in mind, the following strategies and policy directions are recommended considering the current context of the communities and the ambitions by governments and development partners for universal electricity access in the region.

5.1. Establish community based installation and maintenance cooperatives

The lack of experienced maintenance experts coupled with the absence of nearby services speedy for the communities is becoming a key challenge for the sustainable supply of electricity by the systems. This challenge can be resolved using two models.

The first model is by developing mechanisms to create awareness of the local community on how to operate and conduct simple maintenance of the systems. Sometimes, there are very simple faults that can easily be repaired without the need for skilled maintenance experts and providing sufficient training for the end users will solve the problems faced by the communities. This can be achieved by developing a legal framework that last mile distributors and installers to provide complete training package during commissioning of the solar home systems. In order to make this model successful, there must be strong monitoring and evaluation mechanisms in place by the district authorities. In addition, the government and development partners could fund such training on a regular bases so that users are kept updated.

The second model is by developing business and financial models where communities could pay small amount of money in a monthly basis in order to get continues and speedy maintenance services. This can be done through the establishment of cooperatives from the communities themselves by providing sufficient training on maintenance and operation of SHS. Members of the cooperatives can work this parallel to their regular duties such as farming. The cooperatives could also be established in a way that can supply the PV systems, install, and run the maintenance business, which is an effective way to keep the business running and to attract others to join such businesses.

5.2. Develop financial support mechanisms

Some of the surveyed households indicated that the current cost of the PV systems is not affordable. This is becoming the key challenge for facilitating energy access as most of the communities didn't afford to buy the technologies. Financial support are commonly available through loans from government and private institutions and from development partners as funding. Getting funding are always limited and the best way for communities to get access to finance is through loans. However, the financial institutions and private developers have to consider and assess different business risks such as country risk, market risk, money or interest rate risk, project risk, and foreign exchange risk etc as per the study by [28]. In addition, financial institutions create a package that includes the repayment terms, the interest rate, the repayment schedule and any guarantees. Considering these requirements by the financial institutions and the demographics of the communities makes the loan process very challenging and difficult.

Therefore, creating a conducive environment for both the financial institutions and the communities is a daunting task but the government should try to balance the requirements of both parties and develop an effective policy if its ambition of universal access to clean and renewable energy is to be achieved. Some of the internationally proven and effective financial mechanisms that can be implemented by the government are: Develop strong renewable energy institutions that can implement the policies at all levels in coordination with private sector to local, regional and national level authorities; decreasing investor investment cost through direct subsides, tax exceptions, green certificate schemes, feed-in-tariff; Increasing investor confidence by guaranteed minimum prices for electricity from renewable energy for a certain period; Diversifying guarantees to reduce investor risks etc. If such mechanisms are in place, private financial institution will be willing to support the communities and providing loans and private developers will be attracted to this business so that collective action by these stakeholders will ensure facilitation of energy access to the remote areas in the form of off-grid energy systems such as solar home systems.

5.3. Develop incentive packages for research and development and local manufacturing

Research and development has critical role in supporting the adaptation and innovation of technologies to local needs and in developing the capacity of the manufacturing sector [29]. According to [30], research, development and innovation programme are considered as a key strategy to facilitate localization of manufacturing renewable energy technologies. However, considering the huge resource requirement for research and development, financial support from government organizations in the developing world and private sectors is very limited. Therefore, the government should develop effective incentive packages in order to attract private organizations and developing partners to enter to this sector. Some of the key incentive mechanisms that could be implemented to improve capacity of research and development in the region are providing grants specific to research and development, tax deductions for investments in research and development, subsidized loans for procuring high tech research facilities etc.

Specific incentives for the manufacturing industry is also considered as a key driver to attract investors that have the technological capability to produce solar energy technologies. Localization of all or some of the components of solar technologies have huge economic implications such as lowering the cost of the technologies by reducing the transport cost, creating job opportunities, and minimizing the lack of availability of technologies for end users for example in the times of unprecedented crisis and disruption of international supply chain such as the circumstances created by the COVID-19 crisis. For this reason, the development of local capacity to manufacture solar energy technology is important than ever if energy access to the remote communities is to be achieved. While the main competitive advantage must come from creating the best business environment and providing seamless investor services, developing specific incentive packages can strategically attract the development and manufacturing investment into the region. The investment incentives specific for the manufacturing sector may include:improving training institutions to provide ready to start industrial workforce, renewable energy technology focused land arrangement for investors at lower rent, establishing job seekers registry platform and linking them to investors, reduction of income tax, improving quality of support services such as power supply, water supply and road infrastructure, which are key for sustainable production and competitiveness of the companies.

6. Conclusions

This study has focused mainly on the rural communities that have solar home systems (SHS) and explores the key sustainability challenges associated with the utilization of the systems. This has been achieved through a field questionnaire survey. A sample of 398 households were considered from 25,586 households who have SHS. The study found out that majority of the surveyed communities are aware of the benefits associated with the utilization of SHS. However, nearly 30.9% of the respondents indicated that they have insufficient knowledge of the technology to maintain and operate while about 25.9% the respondents believe that there are no reliable maintenance experts. High maintenance and installation costs are also considered as the key challenges with 18.1% and 17.9% of the respondents respectively. Other challenges include high initial investment cost, lack of local manufacturing, frequent failure of the systems, high maintenance and installation costs, lack of spare parts with varying degree of the number of respondents for each challenge. These key challenges are affecting the market diffusion and sustainability of the systems.

It is clear from the policy direction of the country that there is high political willingness to diversified energy access through grid and off-grid energy systems based on the topography and living conditions of the population. For example, the government recently introduced National Electrification Programme where off-grid energy systems are considered as the key for facilitating energy access to remote population of the country. However, such plans and strategies lacks concrete measures and previous plans has failed to achieve its anticipated objectives because such plans and policy directions are not supported through evidence based facts and doesn't consider the socio-economic facts of the region. Unless there is concrete implementation measures supported by internationally proven successful mechanisms such as financing, incentives and other related strategies, the ambition of the country will not be easily achieved. Therefore, considering the key challenges identified as part of this research, some internationally proven strategies and policy directions are recommended in this paper. With proper development and implementation of these recommended policy directions, there is huge opportunity for Ethiopia to fulfill the ambitious plan of universal access through off-grid energy systems and achieve one of the sustainable development goals that stipulate facilitation of the implementation of modern, affordable and sustainable energy to the society. This will have significant co-benefits for the nation by creating job opportunities and reducing the cost of the technologies consequently supporting the facilitation of energy access in the region.

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