Fall 2021

DEVELOPING SUSTAINABLE SOLAR-POWERED ELECTRICITY FOR RURAL ETHIOPIA

Yonas Workie Cherenet

Developing sustainable solar-powered electricity for rural Ethiopia

Case study

Designing decentralized solar energy solution for a remote village of Maji community

Draft of Capstone paper

Regis University Masters in Development Practice

Yonas Workie

September 2021

Table of contents

List of Figures

List of Tables

List of Acronyms

AC	Alternative Current
ADRA	Adventist Development and Relief Agency
BSc	Bachelor of Sciences
CEO	Chief Executive Officer
COC	Certificate of Conformity
DBE	Development bank of Ethiopia
DC	Direct Current
DOSES	Decentralized Off-grid Solar Energy Solutions
EEA	Ethiopian Energy Authority
EECMY DASSC	Ethiopian Evangelical Church Mekane Yesus Development and Social Services Commission
EEP	Ethiopian Electric power
EEU	Ethiopian Electric Utility
EMA	Energy Market Accelerator
ESEDA	Ethiopian Solar Energy Development Association
GDP	Gross Domestic Product
GHG	Green House Gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GNI	Growth National Income

GOGLA	Global Off-Grid Lighting Association
GTP	Growth and Transformation Plan
HiLCoE	Higher Learning Center of Excellence
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Financial Corporation
IRENA	International Renewable Energy Agency
LCOE	Levelized Cost of Electricity
MDC	Maji Development Coalition
MDOSEP	Maji Decentralized Off-grid Solar Energy Project
MFI	Micro Finance Institution
MOWIE	Ministry of Water, Irrigation, and Energy
MSc	Masters of Sciences
NEP	National Electrification Program
NGO	None Governmental Organization
NRECA	National Rural Electric Cooperative Association
PAYGO	Pay As You Go
PPP	Purchasing Power Parities
PV	Photovoltaic
REF	Rural Electrification Fund
SDG	Sustainable Development Goal

SEF	Solar Energy Foundation
SHS	Solar Home System
SME	Small and Micro Enterprises
SNNPR	Southern Nations and Nationality Peoples' Region
STM	Solar Technologies Manufacturing PLC
STT	Sun Transfer Tech
SWOT	Strengths, Weaknesses, Opportunities, and Threats
TVET	Technical and Vocational Education and Training
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USD	United States Dollar
WASH	Water, Sanitation and Hygiene
WSHG	Women's Self-Help Groups

List of symbols

GW	Giga Watt
KM	Kilo meter
KW	Kilo Watt
kWh/m2.a	Kilo Watt hour per square meter annual
kWh/m2/day	Kilo Watt hour per square meter per day
Kwh/month	Kilo Watt hour per month
Kwh/year	Kilo Watt hour per year
KWp	Kilo Watt peak
MW	Mega Watt
W	Watt
W/m2	Watt per square meter
Wp	Watt peak

DEVELOPING SUSTAINABLE SOLAR-POWERED ELECTRICITY FOR RURAL ETHIOPIA

I. Personal statement

My name is Yonas Workie from Ethiopia, I received my Bachelor of Sciences (BSc) in Industrial Engineering from Bahir Dar university in 2002, a Post Graduate Diploma in Computer Science from Higher Learning Center of Excellence (HiLCoE) School of Computer Science and Technology in 2007, and a Masters of Sciences (MSc) in Mechanical Engineering, Industrial Engineering major from Addis Ababa University in 2015. Currently, I am pursuing a Masters in Development Practice at Regis University, USA and I am in a 2021 graduating class.

From 2002 until 2008, I have been working for an Ethiopian private solar company called Lydetco Plc which is the first solar business company in Ethiopia. During my stay as a Sales Engineer and Technical Director I have been able to complete many large-scale solar projects such as solar water pumping, solar systems for rural health centers, schools, and offices where I developed my technical and business skills in the solar sector. Then for three years from 2010 to 2012 I have worked for a non-profit organization called Stiftung Solarenergie (Solar Energy Foundation Ethiopia) as a Technical Director, during my stay in this company I was able to achieve distribution of thousands of Solar Home Systems (SHS) for rural communities. Since 2011, senior staff of the foundation including myself decided to establish our own solar business company called Sun Transfer Tech Plc (STT) with an objective of reaching more rural communities with off-grid solar energy solutions in a sustainable manner. The company was officially established in December 2011, and since then I have served as Managing Director for STT. Some of the major activities that STT has completed to date include system sizing, import, and installation of more than 6,000 solar lanterns (1-to-3-watt capacity), more than 1,000 solar home systems (10-to-100-watt capacity), large scale solar projects including 16 solar water pumping systems (4-to-20-kilowatt peak (kWp) capacity), and a 20 kw three phase solar system for a farmers training center for a development organization, and many other projects. Table I.1 below shows some of the projects that STT has completed.

Table I. 1 STT's major solar projects

Picture	**Year**	**PV Capacity**	**Location**	**Project type**
 	2019	Two sites each with 9.88kwp,	Afar regional state, Ethiopia	Solar water pumping system sizing, import, installation, commissioning and training
 	2013 - present	More than 6,000 lanterns, more than 1,000 solar home systems	Various rural homes Ethiopia	Solar home systems and lanterns

Picture	Year	PV Capacity	Location	Project type
 	2019	8 sites each with about 4kwp system	Harari, Ethiopia	Solar water pumping system for 8 sites each 4 kWp capacity, sizing, import, installation, commissioning and training
 	2019	10 sites each 1.3 kw photovoltaic (PV) system	Various regions in Ethiopia	Domestic rooftop solar PV System, for national parks, installation service

Picture	Year	PV Capacity	Location	Project type
 	2017/18	21 kWp, and other 4 sites each 15 kWp	Tigray region, Ethiopia	Solar water pumping system sizing, import, installation, commissioning, and training
 	2016	10 sites each 640 Wp	Somali region, Ethiopia	Solar school system for refugee camps, sizing, import, installation, commissioning and training

Picture	Year	PV Capacity	Location	Project type
 	2013	20 kWp, three phase PV system	Close to Addis Ababa, Ethiopia	Solar power system required to power a Non-Governmental Organization (NGO) farm training compound, import, sizing, installation, commissioning and training

Currently STT is working on a project in collaboration with a USA-based-NGO called MDC (Maji Development Coalition) and Ethiopian based NGO called SEF (Solar Energy Foundation) to design and implement decentralized solar energy solutions for a remote village of Maji community in Ethiopia. I am interested in developing sustainable solar-powered electricity for rural Ethiopia, using the project mentioned above as a case study. Maji community is located in SNNPR (Southern Nations and Nationality Peoples' Region) as shown in Figure I.1 below. I will study the barriers and opportunities to the current solar pilot project activities done by the companies. The project is expected to provide: 1) access to solar based on feedbacks from community members in focus group discussion to check their preference on SHSs size and costs; 2) water pumping from a borehole to selected water points close to the community; 3) access to productive use of solar energy for various businesses such as workshops, cell phone charging stations, and barber shops; and 4) solar access to local service institutions such as hospitals, schools, local government offices. My work for this capstone paper will be to study the barriers and suggest possible solutions to see the sustainability and feasibility of such decentralized solar energy solutions through the case study.

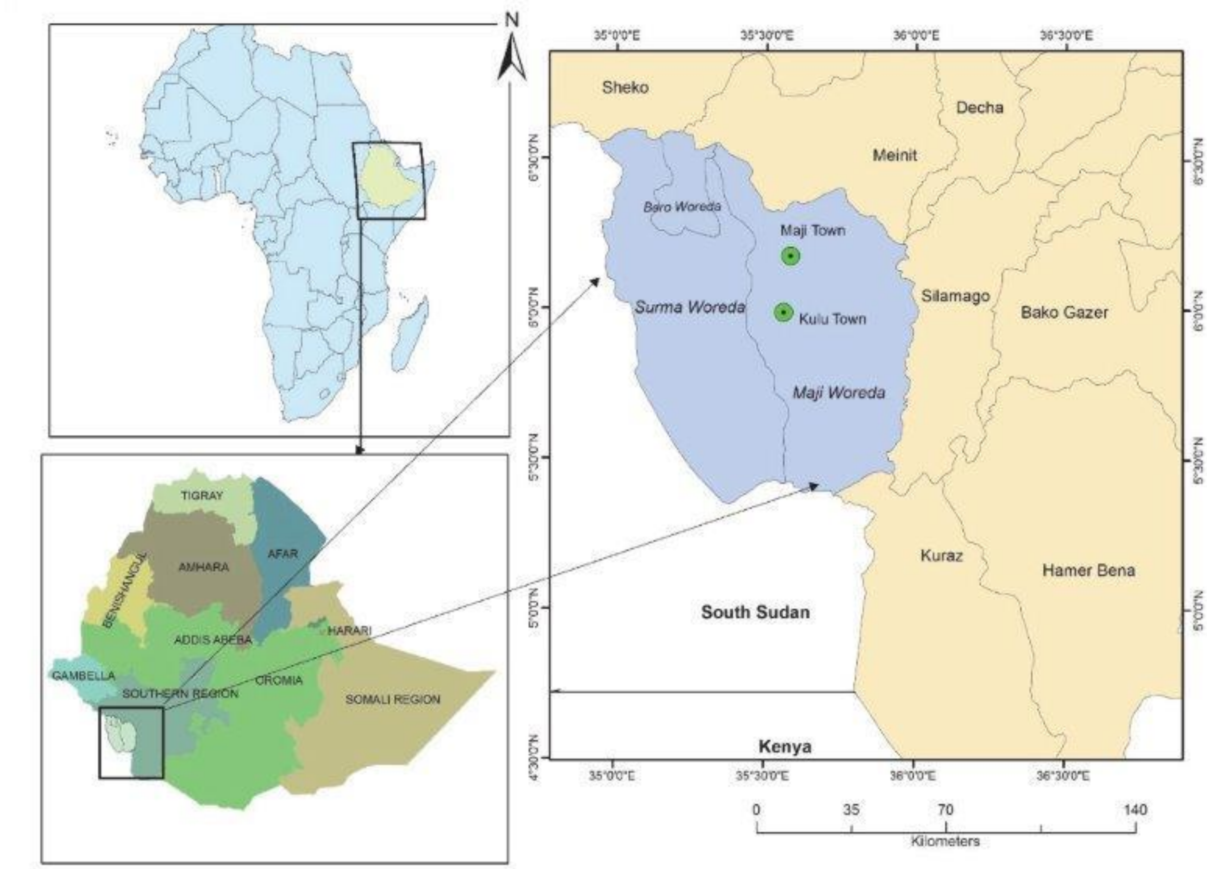


Figure I. 1 Bench Maji Zone in SNNPR, Ethiopia (Tariku, 2018)

II. Acknowledgement

I acknowledge the generous financial support for my education from Institute of Electrical and Electronics Engineers (IEEE) Smart Village and Regis University. I would like to thank my adviser, Professor Joshua Knight, for your patience, guidance, and support. I have benefited greatly from your wealth of knowledge; I am extremely grateful to have faith in me over the year. I would like also to thank my second reader Prof. David Gipson for your meticulous editing, I have benefited a lot from your expertise and personal experience about Ethiopian rural off-grid situation. Special thanks to MDP Program Manager Prof. Nina Miller and the entire team for your patience and understanding during the three years of effort that went into the production of this capstone paper. And finally, thanks to my wife and kids and numerous friends who endured this long process with me, always offering support and love.

III. Executive Summary

Ethiopia has a population of more than 112 million people (2019), which makes the country the second most populous nation in Africa after Nigeria, and nearly 80% of the population live in the rural area. The current electrification status of Ethiopia shows only 45% of the country is electrified out of which 34% on grid and only 11% off-grid. As part of National Electrification Program 2 (NEP-2), the government's off-grid program provides a strategic plan for the use of mixed off-grid energy solutions of which about 30% is planned to use decentralized off-grid solar energy solutions such as solar home systems and standalone solar applications for rural household use and small-scale business (MOWIE, 2021a).

The main objective of this capstone paper is to identify the barriers in developing sustainable solar-powered electricity for rural Ethiopia and to review solutions and access the practical challenges using a case study called "Maji Decentralized Off-grid Solar Energy Project (MDOSEP)". The findings in the case study showed that even though there are many challenges in providing solar solutions for an entire rural community, it is possible to have an impact step-by-step using different approaches. The project used PAYGO payment option for distribution of Solar Home Systems (SHS) in which customers pay a deposit, and commit to making ongoing payments, and collaborated with the private sector, NGOs, and regional government agencies to raise funds for large scale community based solar solutions. The project in the case study has been able to achieve distribution of more than 300 SHSs, installation of a 15.6 kWp solar water pumping system for drinking and a 33.3 kWp solar system for Maji Hospital. The project started engaging Women Self-help Groups and working to reach out to more households and serve community needs in the area.

1. Literature Review

1.1. Introduction

1.1.1. Global solar energy outlook

When we look at the global rural and urban electrification rate, sub-Saharan Africa is far behind compare to those of developed and developing nations in Europe, and Asia, in developing countries, the proportion people who are living in the rural area increases while the electrification rate decreases. The rural electrification rate of sub-Saharan Africa in 2014 was 18.9% which is far lower compared to the developing countries as a whole which is at 67.4% and forecasted data shows that this gap will not decrease until 2030 (Pillot, Muselli, Poggi, & Dias, 2019).

The current global renewable energy trend shows a significant increase in terms of installed renewable energy capacity within the last 20 years, for example Figure 2 shows the installed PV and wind capacity in 1980 was almost none, but in 2016 it becomes about 750 Giga Watt (GW). Currently global energy issues will have prospective solutions from renewable energy sources that are relatively unlimited and have very low Green House Gas (GHG) emissions. Establishment of The United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol in 1970s has led to the rise of renewable energy systems starting in 1980s as shown in Figure 1.1, in which GHG reduction is targeted by the industrialized nations (Pillot, Muselli, Poggi, & Dias, 2019).

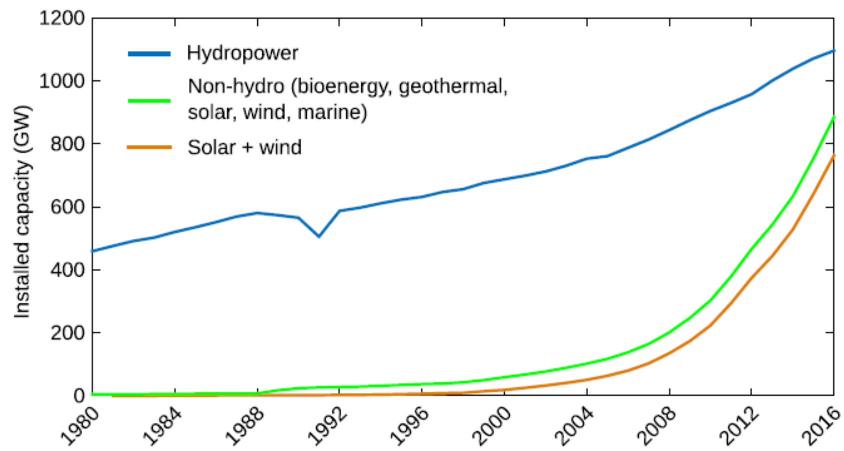
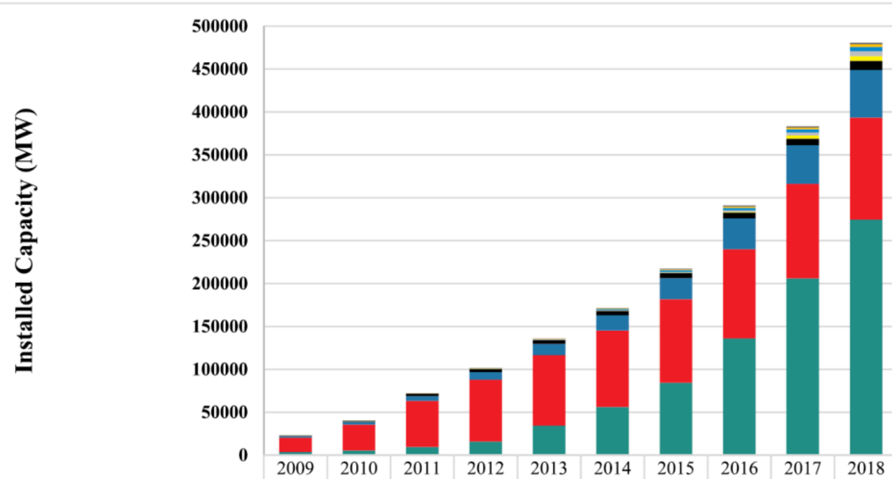


Figure 1. 1 Global renewable energy trend in installed capacity from 1980 to 2016 (Pillot, Muselli, Poggi, & Dias, 2019).



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Central America + Caribbean	48	75	109	168	267	341	922	1149	1490	1726
Middle East	36	85	208	269	512	799	1047	1529	2076	3125
Africa	108	195	268	347	661	1559	1926	2968	3778	5122
South America	15	42	60	157	188	470	900	1545	3422	5471
Eurasia	5	6	8	13	20	49	316	936	3726	5701
Oceania	338	1100	2492	3826	4605	5352	6073	6854	7571	10601
North America	1734	3159	5708	8963	13051	17943	24374	36008	44944	55386
Europe	16835	30119	53616	71848	82018	88877	97367	103853	110299	118840
Asia	3697	5495	9609	15980	34486	56207	84449	136135	206010	274647

Figure 1. 2 World regional overview of installed PV capacity in MW from 2009 to 2018 (Khan, 2020)

The installed PV capacity trend from 2009 to 2018 shows significant increasing in Africa and Asia as shown in Figure 1.2 above, however, Africa which is a continent with one of the highest solar energy resources in the world with an average annual solar horizontal irradiation value of about 2000 kilo watt hour per meter square shows the least installed PV capacity with only 5122 Mega Watt (MW) compared to most of the regions, and it needs more investment to use its potential (Khan, 2020).

Solar PV panels are used to convert sunlight into electrical energy. In the 1970's, PVs were used to power small items like calculators, and then it became popular for small lanterns and solar home systems (SHSs) for off-grid applications. Currently PVs are used for many applications in the area of off-grid and on-grid energy demands (PV systems that can be connected with the existing grid either to feed to the grid or for self-consumption or both). There are many Balances of System (BOS) components in a PV system. BOS are all components of photovoltaic system other than the photovoltaic panels. BOS includes storage batteries, electrical connections, mountings, and a means of regulating or modifying the electrical output. Within the past decade the installed capacity of solar photovoltaic (PV) systems has grown from 23 Giga Watt (GW) at the start of 2010 to around 600 GW in 2020 globally (El Bassam, 2021).

1.1.2. Africa solar energy outlook

Africa has the least access to electricity compared to any continent in the world; currently almost 600 million people in Africa lack access to electricity as shown in Figure 1.3 below. There has been some progress in several countries like Kenya, Ethiopia, Ghana, Senegal and Rwanda, Figure 1.4 shows that Kenya will achieve 100% universal electric access by 2023; Ghana, Senegal, Rwanda and Ethiopia by 2030, but that the population growth rate overtakes the access rate to modern energy services (IEA, 2020). For example, almost in all regions in Ethiopia the electrification rate was 75% to 50% slower than population growth rate from 2014-2019 (NASA , 2020).

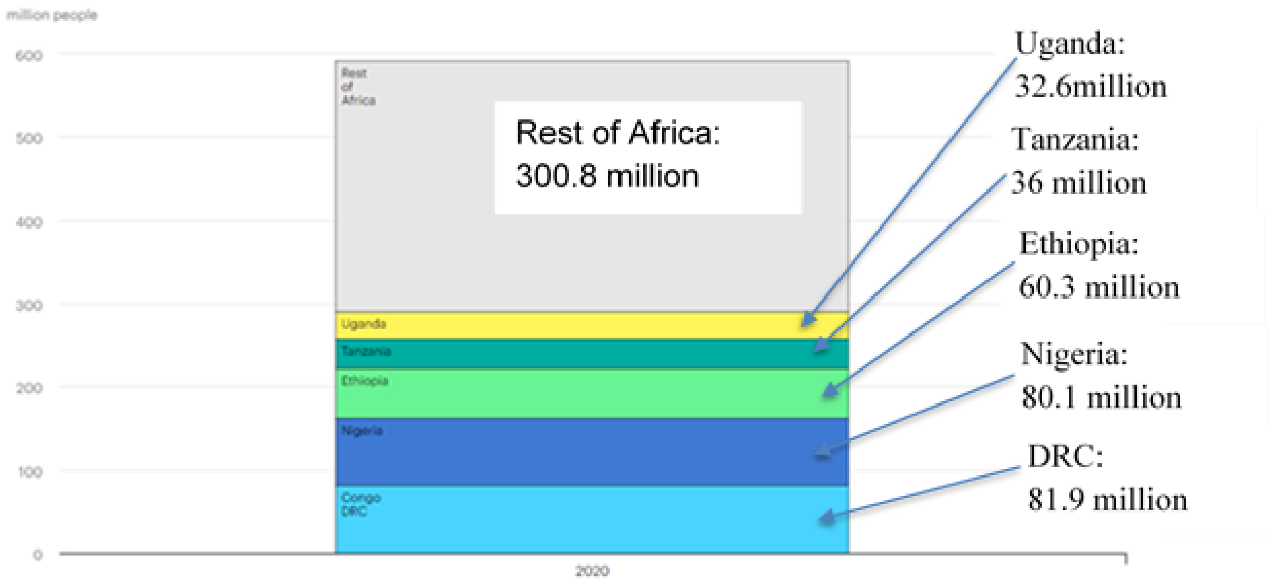


Figure 1. 3 Population without access to electricity by country in Africa, 2020 (IEA, 2020)

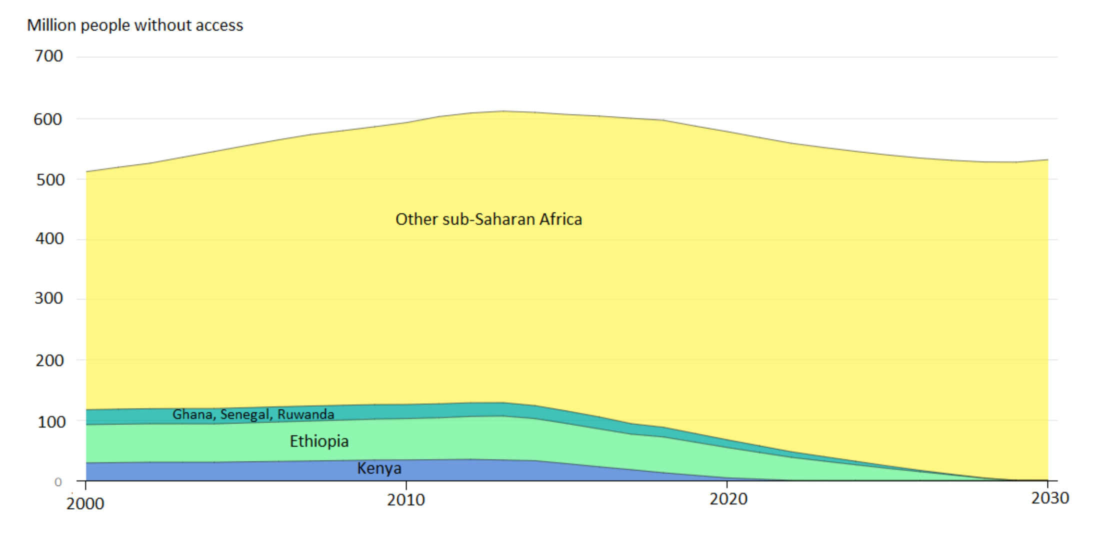


Figure 1. 4 Number of people without access to electricity in sub-Saharan Africa (IEA, 2019)

Africa has one of the best solar irradiations (solar irradiation refers to the amount of solar radiation received from the Sun per unit area.) in the world, its north, south and east Africa with desert, Sahelian and tropical climatic condition has long sunny days with the best solar irradiation values. Figure 1.5, 1.6and 1.7 shows Ethiopia has one of the highest irradiation intensities in the world with an average annual global horizontal irradiation value of 2,000 kilo watt hour (SOLARGIS, 2020)

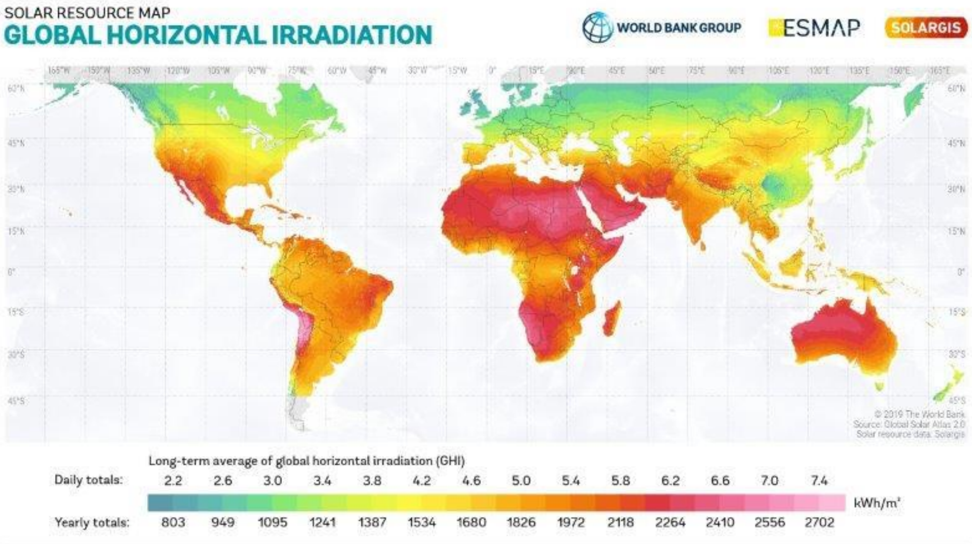


Figure 1. 5 Global Horizontal Irradiation (SOLARGIS, 2020)

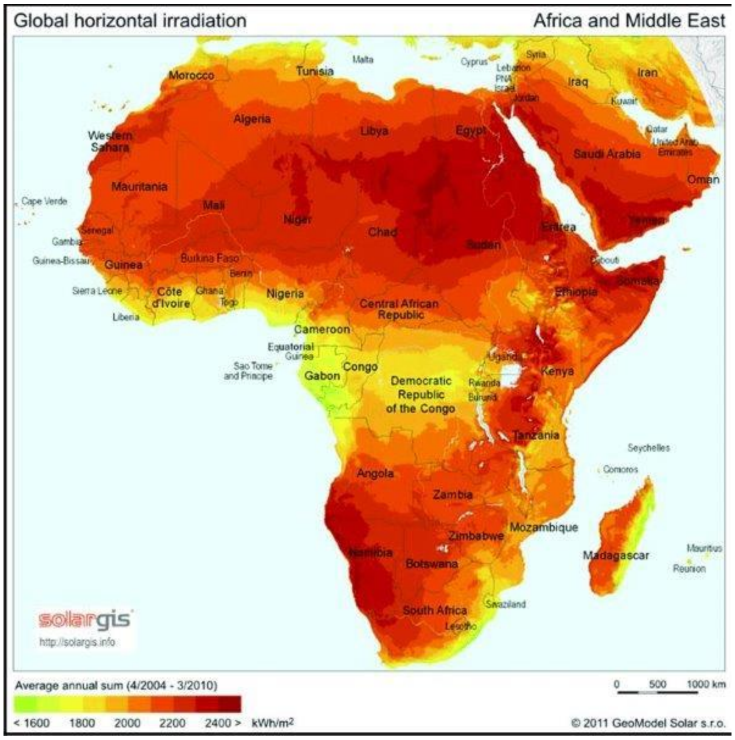


Figure 1. 6 Africa's global horizontal solar irradiation map (SOLARGIS, 2020)

1.1.3. Ethiopia's rural electrification strategy

Ethiopia's National Electrification Program (NEP-II) - Implementation Roadmap (IRM) is an action plan focused on achieving 100% universal electricity access by 2025 (MOWIE, 2021a).The Ethiopian government also has an ambitious plan to expand access to off-grid solar energy to rural homes and enterprises, according to its Growth and Transformation Plan (GTP II), the energy access goal includes 3.6 million solar lanterns; 400,000 solar home systems; and 3,600 solar photovoltaic (PV) systems for rural health centers, schools and other government service centers by 2020 (Lakew, Hailu, Hailu, & Carter, 2017). Even though, there is no concrete information at the moment if these GTP II targets were meet 100% or not, the economic slowdown in the country seen in the last three years due to various reasons such as, political instabilities, COVID 19 will likely be an obstacle to achieve the targets as expected.

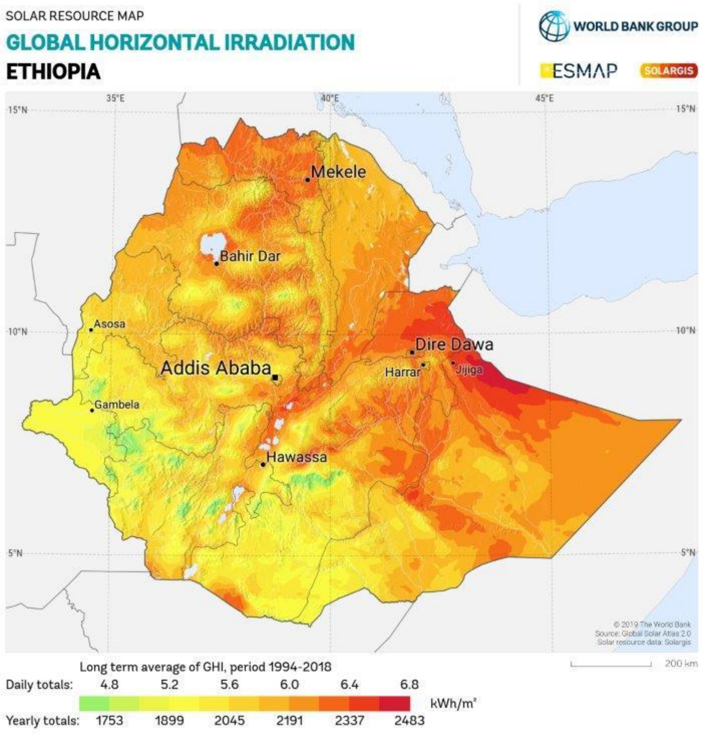


Figure 1. 7 Ethiopia global horizontal solar irradiation (SOLARGIS, 2020)

1.2. Benefits to the sustainable use of Decentralized Off-grid Solar Energy Solutions (DOSES)

1.2.1. Social

Household use of DOSES has an essential social impact, for example, solar lanterns and solar home systems (SHSs) provides safe and brighter light output compared to candles and kerosene lamps. Children can have longer hours at night to study and monthly expenditure for kerosene and candle and dry cell batteries will be reduced, a study in India shows children study period was increased by 30minutes while monthly kerosene expenditure decreased by 0.27 USD (Sharma, Choudhary, Kumar, Venkateswaran, & Singh Solanki, 2019) and a study done by GOGLA (2018), in Kenya, Mozambique, Rwanda, Tanzania and Uganda also shows 84% of households with children report that they have more time to do their homework. Solar powered TV, radio and cellphone are increasingly becoming the means for rural houses to access information about health, family planning, nutrition, and weather forecast (Khan, 2020).

Solar energy technologies have many social benefits and it impacts several groups of Sustainable Development Goals (SDGs) which are a collection of 17 interlinked global goals designed to be a "blueprint to achieve a better and more sustainable future for all" as shown in Figure 1.8. The SDGs were set up in 2015 by the United Nations General Assembly and are intended to be achieved by the year 2030. Solar home systems provide clean and brighter lights (SDG7-Clean Energy), community based solar systems such as water pumping provides access to clean water and sanitation (SDG6-Clean Water), solar powered school facilities provide access to quality education (SDG4-education) and solar powered health facilities can provide quality health services (SDG3-health). Women and children are among the household members who suffers most from burdensome task of traveling long distance 3 to 10 kms to buy kerosene, and collect firewood, due to these tasks they are also among the most likely to face sexual violence, and hence use of solar technologies will make their life easier (Adenle, 2020).

1.2.2. Economic

Studies show there is economic benefit from SHSs to rural households. Some of the benefits are extended working hours particularly for women, increase overall household income due to reduced expenditure for kerosene lamps, candle lamps and dry cell batteries and additional income from charging cellphones through SHSs (Khan, 2020). A study completed by GOGLA (2018), in Kenya, Mozambique, Rwanda, Tanzania and Uganda among SHS users indicated that 58% of them were able to generate additional income, because some of them were able to spend more time at work, others were able to be engaged in more than one activity. The study also revealed that within three months 36% of the households already generate additional income with an average monthly income of 35 USD (GOGLA, 2018a).

Productive use of DOSES provides several economic benefits to the rural communities, as per a definition by Energypedia (2018) productive uses of electricity is "agricultural, commercial and industrial activities involving electricity services as a direct input to the production of goods or provision of services." and it impacts many SDGs (SDG1-Poverty, SDG2-Hunger and SDG8-Economic Growth). Solar phone charging stations, solar systems for rural kiosks, barbershops, wood/metal workshops will create jobs and promote economic growth to many people in the rural areas (Adenle, 2020).

Figure 1. 8 Sustainable Development Goals

Solar energy technology is essential and is very helpful in locations where there is no grid connection to electricity, and it is a general fact that solar power can increase productivity in agriculture and facilitate agro-processing for the rural community (EMA, 2020).

Some of the examples for the productive use of solar energy seen in India include:

- Women in India use solar energy to run poultry farms which was key to increase productivity. The idea is the solar energy will give additional and longer hours of light which will enable the chickens to grow fast and lay more eggs.
- Vegetable chilling center made of an insulated shipping container which was powered by a solar panel as shown in Figure 1.9.
- Simple processing machines that are connected to solar power can create thousands of jobs. In India, productive uses such as a sugarcane juice maker, blacksmith, sewing Machines, etc. were powered by solar energy.
- Rural blacksmith in rural areas use solar power to produce their products. They mostly produce farming equipment.

Figure 1. 9 Indian example of a solar powered vegetable chilling center (EMA, 2020)

In most developing countries agriculture is the main economic activities. therefore, improving irrigation is key to generate additional income, moving away from rainfed irrigation to using solar water pumps for irrigation will maximize agricultural productivity (GOGLA, 2018b). For example, GOGLA in its report (2018b) shares a story of two young Kenyan brothers who decided to buy a small solar water pump for irrigation with a loan because their previous experience using petrol pump and treadle pump to irrigate their vegetable farm was not successful due to high and unpredictable costs of petrol and labor. The brothers were successful by using the solar pump as they were able to diversify their vegetable mix and sell 95% of their harvest keeping the 5% for themselves, at the time when they were not using the solar pumps, they rent them to either a farmer (at 4 USD/day) or construction (at 10USD per day), the brothers were able to pay their loan on the solar pump in less than one year. An example of a young entrepreneur irrigating his farm using a small-scale solar water pump is shown in Figure 1.10 below.

Figure 1. 10 Young entrepreneurs in Africa using small scale solar pumps for irrigation (GOGLA, 2018b)

In Ethiopia there is high market potential for productive use of solar energy, especially for irrigation, in which agro- processing activities such as grain milling, injera baking, milk colling and coffee washing are very essential, and it is estimated that the demand for solar appliances to run such agro-processing activities is up to $380 million USD (Africa Clean Energy Technical Assistance Facility, 2021). In most rural Ethiopia diesel run grain mills are the only way to mill grains such as maize, wheat and teff which needs to be milled in to flour before being consumed, replacing diesel run mills with solar run mills will have huge cost saving advantage because the energy consumed per unit mass is lower for electric mills compared to diesel run mills (Borgstein, Mekonnen, & Wade, 2020). An example of a solar powered grain mill is shown in Figure 1.11 below.

Figure 1. 11 Example Solar-Powered Mill from Agsol (Agsol Solar-Powered Mill, 2021)

1.2.3. Environmental

Solar energy technologies have environmental benefit which is directly linked with SDG7-Clean Energy which has also link to SDG 3-Health and SDG13-Climate. Indoor pollution due to use of kerosene lamps, wood and charcoal is the major issue in rural areas with increased diseases such as heart disease and lung cancer. Another major impact will be household and community level reduction of CO_2 emission due to use of solar energy technologies which replace diesel generators, kerosene lamps, wood, and charcoal (Adenle, 2020). Studies show in Bangladesh that it was possible to reduce 350,000 tons of CO_2 because of the installation of 1.5 million SHSs and the corresponding reduction of kerosene lamps (Khan, 2020).

1.3. Negative impacts of DOSES

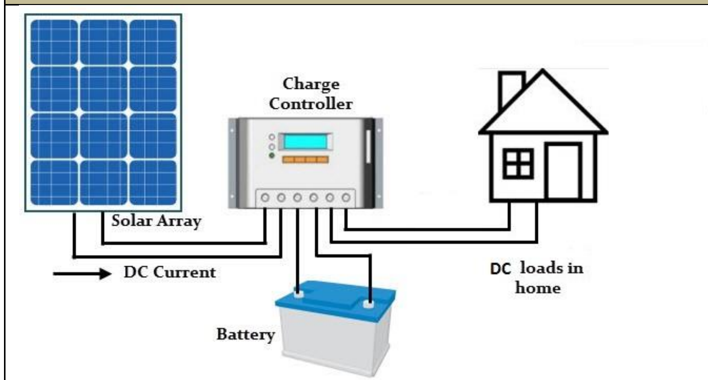
Some of the components of DOSES such as batteries and (compact fluorescent lamps (CFL) of PV components need to properly be disposed of and recycled at the end of their useful life. These products have toxic materials in them that will contaminate ground water and soil if they are not properly managed (Cross & Murray, 2018). Especially in the case of solar batteries, if they are not properly disposed of or if there are no proper recycling facility their environmental and health impacts are significant, the major part lead acid batteries which are lead and sulfuric acid which are both major toxins that cause brain and kidney damage while sulfuric acid can cause burns and other damage to human body upon contact, it also leads to acidification of the environment (which is concentration of toxic chemicals in ground water and air) (Balasubramanian, Clare, & Ko, 2020). In Ethiopia there is no recycling facility and no means to properly collect these products from end users.

1.4. Description of common DOSES

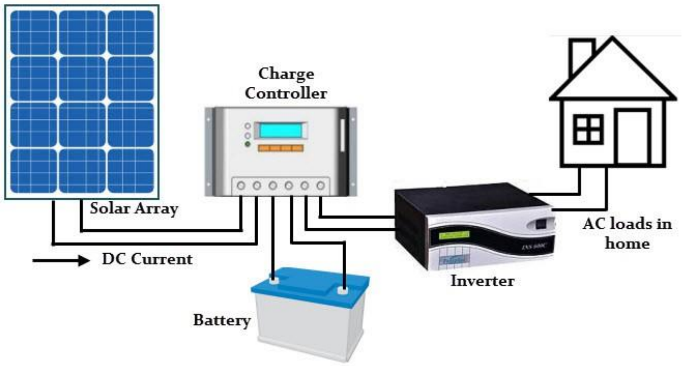
Some of the most popular DOSES products needed for rural communities in Ethiopia are described in detail in Tables 1.1 and 1.2 as follows:

Table 1. 1 Description of common DOSESs for rural household use (Tetra Tech International, 2021)

Solar lanterns	Use and range of power rating
  	- A solar lantern can be one single unit with integrated solar panel, or more units with separate solar panel, a light bulb, and other accessories. - Capacity might range from 1 watt to 3.5 watt peak (Wp). - Used to power one light bulb for an average of about 4 hour/day, mostly with more than one lighting mode (able to adjust the light to different brightness levels such as ultra, high, mid, low and bedtime light). - May include mobile phone charging facility and FM radio.
Solar Pico systems	Use and range of power rating

<table>
<tr><td></td><td>- Pico-systems might have a capacity ranging between 3 Wp to less than 10 Wp.
- Typically include more than one light bulb, mobile charging ports, and music player.
- Usually in the form of a kit with plug-and-play type of assembly which makes it easier for consumers to use.
- They also come with or without pay as you go payment system platform (PAYGO system) Pay As You Go (PAYGO) model is a payment option with credit facilities controlled by a software program in the electronics of Pico solar systems</td></tr>
<tr><th>Solar Home Systems (SHS): Direct Current (DC)</th><th>Use and range of power rating</th></tr>
<tr><td>
</td><td>- DC SHS typical capacity range is 10 Wp – 300 Wp.
- Depending on the capacity, it can support appliances such as: LED lamps, radio, TV, fan, fridge and phone charging etc.
- A DC SHS can be integrated as a kit (solar components bundled together with a set of appliances which are compatible with capacity of the system as shown in the picture

-
- In some cases, larger SHS are specifically sized according to the customer’s energy demand and installed at the place of use.
- They also come with or without pay as you go payment system platform (PAYGO system)</td></tr>
</table>

<table>
<tr><th>Solar Home Systems (SHS): Alternating Current (AC)</th><th>Use and range of power rating</th></tr>
<tr><td>
</td><td>- AC SHS typical capacity range is 300 Wp – 1,000 Wp
- Depending on the capacity, it can support AC appliances such as: fluorescent lamps, TV, fan, fridge, pump etc.
  - An AC SHS can be integrated as a kit (solar components bundled together with a set of appliances which are compatible with capacity of the system as shown in the picture
-


-
- Larger AC SHS are specifically sized according customer’s energy demand and installed at the place of use.</td></tr>
</table>

Table 1. 2 Description of common DOSES systems for productive use (Tetra Tech International, 2021)

Solar water pumping	Use and range of power rating
 Smallholder farmer irrigation pump   	- Depending on the application, the size of a solar pump can significantly vary from a few hundred watts to several kilowatts. - Solar pumps can be owned and used at a smallholder farmer level for an individual farm use or can be used at the community level for Water, Sanitation and Hygiene (WASH) programs. Small pump systems can come with or without payment system (PAYGO system), or smart tap applications using smart water dispensers for community water points. Water dispensers are the device that provides water to the water consumers, also known as the “smartTAP”. Water Dispensers serve as a replacement for existing traditional taps. As the Water Dispenser is solar powered, it needs only a water connection and has a battery inside for use 24 hours per day.

Community based solar water pump with or without dispenser systems	
Solar vegetable chilling center	**Use and range of power rating**
	- Vegetable chilling center made of an insulated shipping container that is powered by a solar panel. - Solar vegetable chilling centers can have different power rating from few hundreds to several kilowatt peak capacity.
Solar grain milling machine	**Use and range of power rating**
	- Solar powered grain mills bring milling services close to rural communities. Grain milling is an existing productive use which usually is provided by diesel powered mills in off-grid areas. For example: in Ethiopia, Maji community Diesel generator run grain milling are the key economic activity for processing crops to use for household cooking. - Solar powered mills can be more profitable as recurrent expense for diesel fuel and engine maintenance would be reduced. - Solar mills can be DC or AC powered. - Usually, the solar mills have a capacity to grind 120 to 150 kg of grains per hour

	- Rated capacity of solar power is about 1.65 kilowatt peak usually with 1.5 kilowatt milling AC motor -
Solar milk chiller	Use and range of power rating
	- Farmers can preserve their milk production using solar powered milk chillers which will improve rural livelihood. Rural farmers face economic loss due to lack of refrigeration. - Solar milk chillers have efficient refrigeration units with hundred to several kilowatt peak solar capacity

Solar chicken incubator	Use and range of power rating
	- Solar powered chicken incubators and brooders are cost effective and user-friendly technology for rural communities - According to different capacity they can be powered from 100 watt to several kilowatt peak solar power - Rural end users can avoid economic loss due to transporting day old chicks with no incubators

1.5. Challenges in dissemination of DOSES

1.5.1. Policy and regulation

In Ethiopia, off-grid and micro-grid solar energy companies face many regulatory requirements with no clear guidance on how to implement off-grid projects. The existence of many rural electrification agencies in various regional states such as in Oromia, Amhara, Tigray, SNNPR etc. have contradictory policies mostly with no clear strategy between off-grid and on-grid expansion has led off-grid solar energy developers and investors to lose confidence to scale up their investments in rural areas (Gordon, 2018).

The National Electrification Plan 2 (NEP-2) 2019 presents an action plan to provide access to 6 million households with off-grid solar solutions such as stand-alone and mini-grid solar systems to achieve 100% electric access by 2025 (USAID, 2019). However, many private solar companies didn’t grow beyond sales of solar home systems, partly because licensing complications in which import and trading of solar energy technologies is not allowed for foreigners. Local private companies have limited capacity and face inconsistent policies such as requirement of redundant agreements between private companies and each regional state agencies and Micro Finance Institutions (MFIs), requirements of 10% cash deposit for the total number of SHS to distribute in a particular region for warranty cases which in most cases these funds are not easy to recover. The existence of such policies in various regional electrification agencies has led to bad relationships among many private companies (Gordon, 2018). Even though Ethiopia has been able to improve its grid expansion in the past 25 years and electricity access reached 48% in 2018, studies show only 34% of rural households were grid connected in

2019. Lack of coordination and integration among various government institutions such as the Rural Electrification Fund (REF), Ministry of Finance, and Ministry of Trade and Industry led to inefficient outcomes in the rural electrification programs. The Rural Electrification Fund (REF) was supposed to coordinate all efforts on rural electrification within the Ministry of Water, Irrigation and Electricity (MOWIE), but there is limited cooperation between REF and various ministries and donors (Pappis et al., 2021).

1.5.2. Financial constraints

Ethiopia has many challenges in terms of financial resources; the country is highly dependent on imports with highly volatile and restricted foreign currency. Import procedures are complicated and inconsistent, and high tariffs abound. The cost of off-grid solar energy solutions has increased due to limited foreign currency and other distribution channel challenges. Studies show that in East Africa the cost of off-grid solar energy solutions rages from $4,000 to $8,000 USD per kw, and almost all solar goods are imported from abroad in dollars, and then sold to local people in a volatile local currency, and hence, often it is not easy for local companies to put a reasonable price tag and therefore, mostly solar products are overpriced by the companies to avoid the business risks. (Mugisha, Ratemo, Keza, & Kahveci, 2021).

According to a study by van de Ven et al (2020) Ethiopia has one of the lowest levels of rural household incomes, and it has the lowest US dollar Purchasing Power Parities per day (USD $ PPP/ day) compared to Tanzania, Kenya and Uganda. An income around the extreme poverty line of USD $ PPP 1.9 is not enough to meet daily basic needs, as per the World Bank report (The World Bank, 2021b) in Ethiopia 30.8% (2015) of the rural population has daily consumption less than 1.9 USD per person, and the national average in 2020 and 2021 is estimated to be 27% . Currently, A 20 watt SHS costs around $177 USD and 50 watt SHS costs around $444 USD for a rural end user and hence poorer communities in rural areas with less than $1.9USD/day income cannot afford to pay 100% in cash for most of the off-grid solar energy solutions. This situation has caused local companies to use the PAYGO model to provide an option for the end user to pay in a three-year cycle, but companies are also forced to apply high interest rates to compensate for the unpredictable local currency, and hence it becomes very challenging for poorer communities to afford solar energy solutions (Mugisha, Ratemo, Keza, & Kahveci, 2021). Lack of government subsidies for poorer rural communities in East Africa also causes the off-grid market to be stagnant (Adenle, 2020).

In summary, most of the challenges in dissemination of decentralized solar energy solutions for rural communities in Africa are linked with implementation of the solar energy products due to foreign currency shortage and lack of governmental support to the poorer communities.

1.5.3. Technical

In Ethiopia there is limited nationwide technical capacity to perform professional solar system design, sizing, installation, and aftersales services due to lack of locally-organized and industry-wide PV training facilities and programs. Most of the available skilled engineers and technicians are located in the capital city of Addis Ababa and hence, regional-level skilled labor for installations and maintenance of larger PV systems is almost non-existent. There is also limited local capacity to perform solar product quality control and testing. Substandard products are common in the market due to contraband trading because there is weak border control and through uncertified importers which affects the acceptance of off-grid solar energy solutions by the wider end users (Shanko, Hankins, Saini, & Kirai, 2009).

The remoteness of many rural villages due to bad road infrastructure makes it difficult to reach rural communities with off-grid solar energy solutions. Lack of technology transfer and limited local solar product manufacturing facilities has led to high foreign exchange spending to import almost all solar products from abroad. However, there are two or three local assembling companies such as Fosera Manufacturing PLC, HelloSolar International and Solar Technologies Manufacturing PLC (STM) but doing low level of assembling activities of solar lanterns and solar home systems. Some of the challenges of these assembly companies are lack of regional and national financial institutions to provide loans, lack of skilled manpower due to limited training facilities (G. Gebreslassie, 2019), lack of incentive to provide tax free privileges for components, and shortage of foreign currency are also some of the challenges (Lakew, Hailu, Hailu, & Carter, 2017).

1.5.4. Networking

Lack of proper and organized communication between private sector and the responsible government bodies to facilitate and implement policies and regulations has led to lack of enough private sector involvement in the off-grid solar energy sector (Gordon, 2018). There is also no coordinated and consistent information flow between national and local government (city, district, village) which limits effective implementation of off-grid solar energy projects and financial resources. To attract foreign investment and international funds for off-grid solar energy. The existing solar energy association established by private companies who are affiliated with solar energy industry is not strong enough to tackle most of the challenges.

1.5.5. Socio-cultural

Rural community participation in the promotion, planning, and dissemination of off-grid solar energy solutions is very essential. Having a network of Women's Self-Help Groups (WSHG) plays an important role in the speedy diffusion of solar home systems to reach marginalized rural areas (Joshi, Choudhary, Kumar, Venkateswaran, & Solanki, 2019). Rural communities' opinion about the functionality of different energy sources is key for designing a mix of decentralized solar energy solutions with maximum satisfaction level and ensure social acceptance of the solar energy solutions. People in the rural areas lack the information and hence has not enough knowledge about the advantage of small scale off-grid solar energy technologies which shows the need for intensive promotion and awareness creation. On the other hand, a study done by Oluoch et al., (2020) shows that decentralized solar energy diffusion are coming from top policy makers which doesn't include the grassroots perspective. Therefore, having community engagement plan in any off-grid solar energy project to involve the local community members particularly the women, through various methods such as Resource Mapping, Focus Group Discussion, Flow Diagrams, SWOT Analysis, and Social Network Analysis etc. will ensure sustainable dissemination of the solar energy solutions and social acceptance of the project (Rahman & Pokrant, 2014). Community resource maps and social maps are important participatory planning tools , using resource maps it will be possible to identify each rural household's existing energy consumption, type of energy and how far the houses are located, and using social maps it is possible to study the household's economic condition (energy expenditure pattern), if they are women led or not, family size, educational status, number of children etc. these information will help to design the technical and financial plan for the required off-grid solar solutions in the community (Rahman & Pokrant, 2014).

In summary, the Ethiopian government has limited capacity in implementing it's polices and regulations to create an attractive environment for solar energy trading. Such limitations include but are not limited to 1) lack of foreign currency access for genuine companies, 2) weak border control against illegal contraband trading of solar energy products, 3) lack of creating consistent working environment in all regional states, 4) unnecessary import delays and costs. If such difficult situations are removed the private sector can a play a significant role in creating employment opportunities and speedup off-grid solar energy access to rural areas (Lakew et al., 2017).

Lack of financial loans which are easy to access through all private banks and Micro Finance Institutions (MFIs) to local companies, small and micro enterprises and end users has been a challenge. Limited local technical capacity in system sizing, repair, and maintenance of off-grid solar energy solutions at the regional level are issues which is affecting the sustainability of off-grid solar energy solutions. There are small number of genuine private solar companies and hence, their solar association has tried to get the solar tax tariff code revised through discussions with responsible government entities such as MOWIE, Ministry of Trade, but it is not strong enough to tackle most of the challenges which have appeared at the policy and regulation level. Most off-grid solar energy projects are not involving the local community at the planning and designing level which usually affects the acceptability and sustainability of projects.

There is lack of enough funding and support from local and international communities through mechanisms like clean energy initiatives such as the Myclimate carbon offset project which supported local projects done by Solar Energy Foundation in Ethiopia through voluntary carbon offset program for the solar home system installations (Sun-Connect, 2013). Such initiatives will make Decentralized Off-grid Solar Energy Solutions (DOSES) competitive in terms of cost and energy output compared to centralized grid electricity. Lack of proper attention to the socio-cultural needs and views of the targeted rural communities affects the success of off-grid solar energy electrification (Boamah, 2020). Even though the cost of solar panels is decreasing globally, the other basic components of DOSESs such as solar batteries, charge controllers, and inverters are not affordable for most households in the rural areas of sub-Saharan Africa (Boamah, 2020). Lack of enough technical capability to provide maintenance and after sales services after DOSESs are implemented, limited availability of spare parts, and options to various size of bundled SHS as per user’s needs are also barriers that affects dissemination of DOSES (Khan, 2020).

1.6. Solutions Provided

The Ethiopian government has an ambitious plan to achieve 100% universal electric access by 2030 and to create a climate-resilient green economy with zero carbon emissions. In order to meet these goals, the government is focused to face four main barriers which are limiting the dissemination of off-grid solar energy technologies: 1) strengthening regulatory and legal framework based on national standards, 2) Rural public awareness campaign on renewable energy technologies, 3) Sustainable Financial Mechanism for renewable energy technologies for rural households, 4) Business incubation to promote greater entrepreneurship for investment in off-grid energy solutions (MOWIE, 2021a).

1.6.1. Policy and regulation

The top-level responsibility for energy issues in Ethiopia is The Ministry of Water, Irrigation, and Energy (MOWIE). Ethiopian Electric Utility (EEU) is responsible for power distribution; the Ethiopian Energy Authority (EEA) is responsible for energy regulation; the Ethiopian Electric power (EEP) is responsible for generation and transmission. Alternative Energy Technology Development and Promotion Directorate is one of the three directorates under MOWIE in which off-grid solar energy is managed (USAID, 2019).

Ethiopia's energy policy vision is to ensure access to affordable, clean, and modern energy for all of its citizens and to become the leading renewable energy hub in the Eastern African region by 2025. In the past 20 years Ethiopia has made significant progress in universal electricity access in connecting rural villages mainly through public investment. However, grid presence in a community doesn't mean actual rural household connection which is still the lowest among sub-Saharan Africa countries mainly due to economic with one of the least per capita income of $850 (2020), geographic challenges due to scattered rural settlements (Ecofys & SNV Ethiopia, 2016). The country has laid out the Rural Development Strategy in 2001, the Rural Electrification Strategy in 2002 and the Rural Electrification Fund (REF) proclamation in 2003. The main aim of these proclamations was intended to address the issue of rural electrification through renewable energy solutions involving both the public and private sectors. The 2001 and 2002 strategies state the importance of rural off-grid solar energy expansion through the private sector. GTP II (2015-2020) is focused on building a Climate Resilient Green Economy (CRGE) in which the country sets a strategy that by 2025 it will be a middle--income country, resilient to climate change impacts and with no net increase in greenhouse gas emissions from 2010 level through diversified strategies that includes off-grid solar energy expansion (Ecofys & SNV Ethiopia, 2016).

Ethiopian National Electrification Program 1 and 2 (NEP 1 and NEP 2) was established in 2017 and 2019 respectively. NEP 2 is a follow up of NEP 1, it is an action plan focused on achieving 100% universal electricity access by 2025. In the action plan, off-grid technologies such as decentralized solar energy solutions, and mini grid technologies were expected to provide access to 6 million beneficiaries by 2025 and the plan also includes a direct finical investment and technical assistance of almost 6 billion USD for on-grid and off-grid expansion. The government new policy scenario under NEP II shows that everyone within 5 kilometers (km) of the existing grid will be connected by 2025 which accounts for 65% of the population, the remaining 35% will be electrified through off-grid technologies. It also shows that everyone within 25 km of the existing grid will be connected by 2030 covering 95% of the population, and the remaining 5% will be electrified through off-grid technologies (Pappis et al., 2021). In practical terms, previous plans to address rural electrification through off-grid solar energy solutions was limited, most expansions were based on grid extension. The total electric access rate reached 45% in 2018, but studies show that in rural area 90% of the population live within 10 km of grid infrastructure, but only 34% of rural households are grid connected in 2019 which shows the “last -mile paradox” (in which the required cost to connect these households is not high compared to the overall grid infrastructure cost) (Pappis, et al., 2021). NEP 2 targets eight million rural households, twelve million smallholder farmers, over forty-five rural health facilities, and over twenty-seven thousand rural schools to provide 100% access using off-grid solar energy solutions by 2030 (Tetra Tech International, 2021). The government’s target to achieve universal electricity access is summarized in Table 1.3 below which shows the off-grid and on-grid access status and forecast from 2017 to 2030 through the National Energy Program in the Growth and Transformation Plans II, III, IV (GTP-II, GTP-III, GTP-IV) (MOWIE, 2019).

Table 1. 3 National Energy Program targets and timetable (MOWIE, 2019)

Time Period		Total House-holds	Grid Conn. Added	Cumul. Grid Conn.	Grid Access Rate	Off-Grid Conn. Added	Cumul. Off-grid Conn.	Off-Grid Access Rate	Total Conn. Added	Total Cumul. Conn.	Total Access Rate
Program	Year	(millions)	(millions)	(millions)	(pct)	(millions)	(millions)	(pct)	(millions)	(millions)	(pct)
GTP II	2017	19.9	0.2	6.6	33%	0.0	2.2	11%	0.2	8.8	44%
	2018	20.4	0.3	6.9	34%	0.0	2.2	11%	0.3	9.1	45%
	2019	20.7	0.5	7.4	36%	0.1	2.3	11%	0.6	9.7	47%
	2020	21.1	0.7	8.1	38%	0.5	2.8	13%	1.2	10.9	52%
	2021	21.6	0.9	9.0	42%	0.7	3.5	16%	1.6	12.5	58%
GTP III	2022	22.0	1.3	10.3	47%	0.9	4.4	20%	2.2	14.7	67%
	2023	22.4	1.5	11.8	53%	1.0	5.4	24%	2.5	17.2	77%
	2024	22.8	1.6	13.4	59%	1.2	6.6	29%	2.8	20.0	88%
	2025	23.2	1.7	15.1	65%	1.5	8.1	35%	3.2	23.2	100%
GTP IV	2026	23.6	1.8	16.9	72%	–1.4	6.7	28%	0.4	23.6	100%
	2027	24.0	1.8	18.7	78%	–1.4	5.3	22%	0.4	24.0	100%
	2028	24.4	1.9	20.6	84%	–1.5	3.8	16%	0.4	24.4	100%
	2029	24.8	1.9	22.5	91%	–1.5	2.3	9%	0.4	24.8	100%
	2030	25.2	1.8	24.3	96%	–1.4	0.9	4%	0.4	25.2	100%

1.6.1.1. Quality standard and customs regulations

Companies that are importing complete off-grid solar system products and manufacturers/assemblers that are importing solar system components need to pass through the customs clearing process. Customs has complicated and bureaucratic process and mostly their officers face difficulty to identify solar products to allow duty free privilege (USAID, 2019).

The customs clearing process involves several regulatory processes and permits which engages several government organizations such as the Ministry of Trade, Ethiopian Customs Commission, Ethiopian Conformity Assessment Enterprise, Ethiopian Energy Authority, and Ethiopian Investment Commission (Tetra Tech International, 2021). The Ethiopian government has strict regulations for importation of standalone solar systems. Importers are required to provide third party quality standard certificates to get duty and tax exemption incentives. Off-grid solar energy solutions imported as complete system need to have certificates like International Electrotechnical Commission (IEC) standards to ensure that they meet the minimum quality standards (Tetra Tech International, 2021). To enforce the minimum quality standard, a Certificate of Conformity (COC) is required as pre-shipment inspection from different accepted international inspection companies such as Standard Global Service (SGS) and Intertek. For smaller system such as solar lanterns and Pico systems (solar home systems up to 15-watt peak (Wp) capacity) later upgraded up to 300Wp, a valid Lighting Global certificate is sufficient. The Ministry of Finance has made tariff regulation revisions in 2021 to provide customs duty exemptions to productive use solar solutions for the agriculture sector including egg incubators, crop milling, chicken brooders, and milk churning machine (Tetra Tech International, 2021).

1.6.2. Financial Investment

The World Bank funded financial sources through Development bank of Ethiopia (DBE) is the main source of foreign currency loans for the private sector to distribute Lighting Global certified solar lanterns and solar home systems. So far, 70,000 solar home system and 1.1 million solar lanterns have been distributed to the rural community in Ethiopia. Micro Finance Institutions (MFIs) and the private sector have also played their role in providing micro loans to the end user for dissemination of the solar lanterns and solar home systems (MOWIE, 2019). However, importation through DBE loan is complicated and it requires collateral and guarantee with up to 12.5% interest rate which is difficult for small scale private companies.

The government needs to support local solar manufacturers by facilitating importation processes, creating incentives by reducing import-related costs, and providing loan facilities from banks. Such initiatives will play a significant role in boosting the sector and hence reducing the unemployment rate (which is expected to reach 21.6 % at the end of 2021) by creating vast job opportunities for many graduating youths that will have positive impact to 70% of undergraduate enrollment in science and engineering that the government is enforcing. Having a local manufacturing facility will also reduce the amount of foreign exchange demand otherwise used for importation of finished solar products. However, responsible stakeholders such as the Ministry of Water, Irrigation and Energy, Ethiopian Quality Standards, Ministry of Trade, Ethiopian Customs Authority, and Ethiopian Solar Development Association need to follow-up on the quality and sustainability of locally made solar products by having well organized local test facilities, and randomly checking products from the market. Importers and manufacturers need to support poor end users by using pay-as-you-go models, and financiers need to expand their support to distributers like local Small and Micro Enterprises (SMEs) who are engaged in distribution and installation of solar lanterns and SHSs through credit facility using Micro Finance Institutions (MFIs) (Lakew et al., 2017).

1.6.3. Technical Training and Capacity Building

The Ethiopian government has been providing some training activities through the Rural Electrification Fund (REF), and many NGOs like Solar Energy Foundation (SEF) and Gesellschaft für Internationale Zusammenarbeit (GIZ) are providing technical solar PV training through international funds which are mostly project based and are inconsistent because it doesn’t have standards and continuity there is not specific information about the number of beneficiaries and the kind of fund. SEF was able to provide six-month training courses on solar PV technology installation and after sales service for about 60 rural solar technicians from 2007 to 2012, and they were employed by the company for its own projects. In 2019, Adventist Development and Relief Agency (ADRA) developed curriculum and conducted training on Solar PV System Installation and Maintenance for Technical and Vocational Education and Training (TVET) schools in Oromia and Tigray regional states for about 40 technical teachers.

1.6.4. Networking

The Ethiopian Solar Energy Development Association (ESEDA), previously called Solar Energy Development Association-Ethiopia (SEDA-E) was established in 2010 as a charity organization, and then re-established in 2019 as an industrial association through the Ministry of Trade. ESEDA was established by the solar industry major players such as solar and thermal system importers, distributers, installers and manufacturers that are strongly affiliated with the solar industry. As per a report by Precise Consult (2019) ESEDA's vision is "to be the preferred entity for Ethiopia solar energy industry", and its mission is "to promote sustainable solar energy access in the nation by enabling solar energy enterprises to provide reliable and superior quality products". However, ESEDA as a newly established association has its own strength such as have committed board members, members have extensive experience and expertise in the industry, and have good relationship with stakeholders but also many weaknesses that needs considerable support from government and non-government organizations to achieve its vision and mission. Some of ESEDA's weakness include lack of clarity on the strategic direction of the association, weak marketing and promotion activities to strengthen association image and create public awareness, weak human resource and financial capability, and the absence of key association processes (Precise Consult, 2019).

The Ethiopian government can certainly increase confidence of the private sector by sharing information of its grid expansion areas so that the private sector will not invest in alternative energy in areas where the government grid will soon be connected.

1.6.5. Socio-cultural

The Ethiopian government has been providing some promotional activities on the dissemination of rural off-grid solar energy solutions through media such as radio and TV to reach out to more rural communities. Most of these awareness creation activities are supported by development partners such as the World Bank and the International Financial Corporation (IFC) (The World Bank, 2018). Many NGOs focus on livelihoods and this becomes one channel for the distribution of off-grid solar energy solutions, for example they supported hundreds of women led small businesses engaged in distribution of solar products to the rural communities where the women are located and they buy solar products from private companies (USAID, 2019). Development organization programs like Solar Sister's women-led empowerment movement that are actively engaged in empowering women through innovation and entrepreneurship in Nigeria, Tanzania, Kenya, and Uganda can be considered as a best practice that help to increase electric access to the poorest communities in Africa. Solar Sister was able to organize and empower more than 5,000 women entrepreneurs through providing various skills like financial management and technical product knowledge. So far, they were able to impact more than 2 million people through distribution of clean cooking stoves, solar lanterns and solar powered cellphone chargers (SOLAR SISTER, 2018). Having a network of Women Self-Help

Groups (WSHG) plays an important role in the speedy diffusion of solar home systems to reach marginalized rural areas (Joshi, Choudhary, Kumar, Venkateswaran, & Solanki, 2019). Community-based projects can also get support from international organization that are focused on community needs. For example, IEEE Smart Village has a unique approach to address rural community needs by providing a comprehensive solution which combines off-grid solar energy solutions with community-based education, and entrepreneurial opportunities while preserving the best of local cultures and heritages. They have supported many entrepreneurs in Africa since 2012 (IEEE Smart Village , 2021).

In summary, Ethiopian government has put different programs and strategies in order to achieve 100% universal energy access by 2025 in which off-grid solar energy solutions are considered as one of the energy sources to address the off-grid areas through private sector. However, the private sector has limited capacity to address the scale of needed to invest in off-grid solar energy sector mainly due to technical and financial limitations, there must be coordinated and consistent policy and regulation among all energy agencies in all regional states of Ethiopia and create favorable working environment for private and international investors. Government needs to work on revising inappropriate regulatory policy, have skilled manpower at the policy-making level and solve customs, quality control and foreign currency issues and need to strengthen the Solar Energy Development Association (ESEDA). Ethiopian government has done positive progress in tariff regulation revisions in 2021 to provide customs duty exemptions to most of the off-grid solar energy solution products and components that will also support local assembly, continuation of World Banks’s funding through local banks credit line to the private sector will also play significant role to scale up the off-grid solar energy projects. Addressing the socio -cultural needs in the rural community by empowering women, participating the local community at all level in the in off-grid solar energy projects will ensure social acceptance and sustainable dissemination of solar energy solutions.

2. Case Study

2.1. Introduction and context

Ethiopia has a population of more than 112 million people (2019), which puts the country the second most populous nation in Africa after Nigeria. It is also one of the fastest growing economies in the region (6.1% in 2020). Even though it is one of the poorest countries in Africa with the least per capita income of $850 (2020), it has an ambitious goal to reach lower-middle-income status by 2025 (upper middle-income level is with a Growth National Income (GNI) per capita between $4,046 and $12,535, and lower middle-income level is with a GNI per capita between $1,036 and $4,045 (2021)). Ethiopia has been able to achieve a broad-based economic growth of 9.4% from 2010/11 to 2019/20, however, its real Gross Domestic Product (GDP) growth has suffered and is down 6.1% in 2019/20 from 9.4% in 2010/11 due to COVID-19 (The World Bank, 2021a).

Nearly 80% of Ethiopians living in rural areas have no access to electricity. Excellent solar conditions enable attractive small decentralized off-grid PV systems for rural populations, in which most rural houses are located in remote and scattered settlements (Lighting Africa, 2020).

Cutting trees for fuel wood for lighting and cooking is one of the major reasons for deforestation in Maji area of Bench Maji Zone in Ethiopia and the use of alternative energy like solar is recommended to conserve forests (Hussen, 2018).

Sun Transfer Tech Plc (STT) a local solar business company, Maji Development Coalition (MDC), a USA based non-profit organization and the Solar Energy Foundation (SEF) a local non-profit organization are collaborating to provide off-grid solar energy solutions in a decentralized approach to Maji Woreda in Ethiopia. The community will be involved in various focus group discussions and decision-making processes. MDC commissioned a basic community needs survey, which revealed that 40% of Maji Woreda households are woman-led and food-insecure (EECMY DASSC, 2017). The MDC business model organizes women's self-help groups, makes solar home systems (SHSs) available at a subsidized rate to participating women, and encourages women to begin income generating activities (IGAs). The electricity businesses will be women-led, and they will have revolving funds available with reasonable service charges. MDC will train young women to run village services such as potable water supply or milling as IGAs or co-ops, in this process they themselves will be part of the decision-making process in the overall design of the project. The project will extend solar PV electricity service to rural households and replace polluting electricity from diesel generators in the towns, provide financing, and deploy a decentralized solar PV solution to serve local needs. The project will also provide training and employment opportunity to local youth for installation and aftersales services. In general, the Maji decentralized solar energy solution project will demonstrate a commercially scalable, replicable development-driven model for Ethiopia’s clean energy development goal of universal access.

2.1.1. Socioeconomic and demographic context of the study area

2.1.1.1. Bench Maji Zone

Bench-Maji Zone is located in the Southern Nations, Nationalities and Peoples Regional State of Ethiopia. Bench Maji Zone is one of the 14 zones which are located in the southwestern state. The zone has 10 woredas and one administrative town (Geremew & Hailemeriam, 2015). Zones are the highest regional administrative level within SNNPR state. Woredas are equivalent to districts and are the second level of administrative units. Kebeles are the smallest administrative unit and are equivalent to town centers or villages.

2.1.1.2. Maji Woreda

Maji community is located in Maji Woreda which is one of the districts in Bench Maji Zone. The woreda shares a border with the South Omo Zone to the east, Surma Woreda to the west, Menit Shasha Woreda to the north and South Sudan to the south as shown in Figure 2.1 below (Geremew & Hailemeriam, 2015).

Maji woreda community comprises twenty-two kebeles (smallest administrative units in Ethiopia) including the woreda capital village called Tum. Maji Woreda has a total population of about 46,248 with about 5,088 households. Maji community has a cellular network tower which is located in Maji for better connectivity, however the network is not reliable and six of the twenty-two kebeles are not covered with mobile service (NRECA International, 2017). Maji kebele is a highland community located about 18 kilometers (km) from the woreda capital of Tum which is relatively a low land community, and it is located about 190 km from the Zone capital city of Mizan Teferi and 760 km away from the capital city of Addis Ababa.

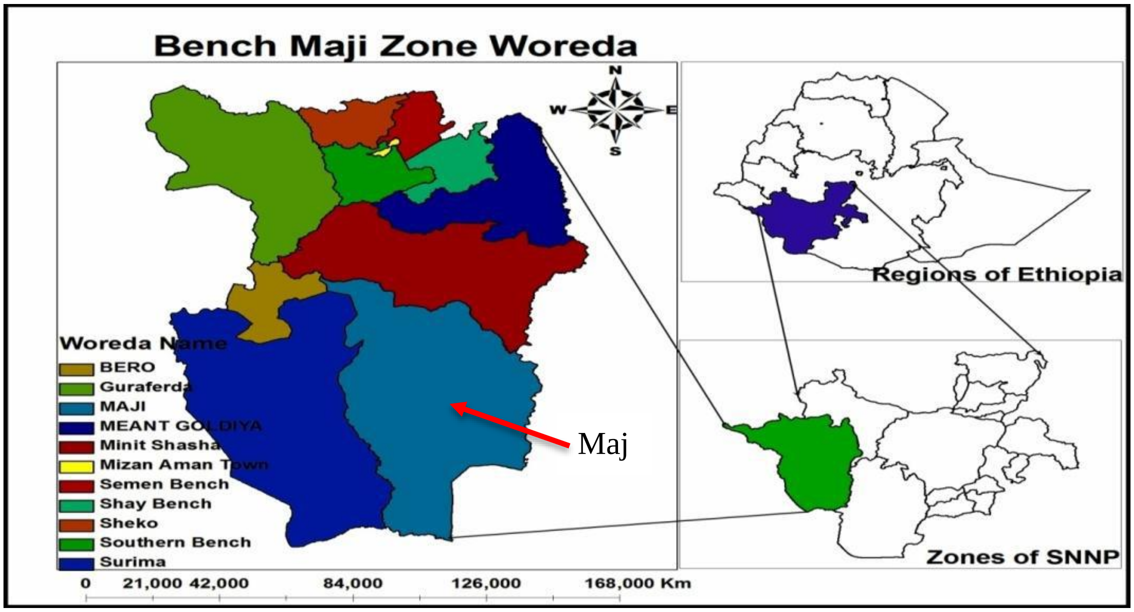


Figure 2. 1 Bench Maji Zone and Maji Woreda (Geremew & Hailemeriam, 2015)

Agricultural farming and livestock are the major economic activities in Maji, local crops include wheat, sorghum, teff, maize and barley while cattle, goats, and chickens are the main livestock. Diesel generator run grain milling are the key economic activity for processing crops to use for household cooking (NRECA International, 2017).

Maji has a number of socioeconomic challenges due to lack of developmental interventions. According to a base line study developed in 2017 some of the challenges are: 1) lack of electricity, 2) social unrest and security issues with its neighbors South Sudan to the south and Surma Woreda to the west, 3) poor infrastructure, 4) lack of access to clean drinking water, 5) lack of quality health and educational facilities, 6) high rate of unemployment, and 7) lack of alternative income sources for women and youth groups (EECMY DASSC, 2017).

2.1.2. Electric power access situation in Maji

Maji is one of the clusters of villages in Ethiopia designated as an unelectrified village (UV) by the Ethiopian Electric Utility (EEU) as show in Figure 2.2 below, currently the EEU is the main on-grid and off-grid electric service provider, the current electrification status of Ethiopia shows only 45% of the country is electrified out of which 34% on grid and only 11% off-grid. The nearest electrical grid interconnection location to Maji is about 80 km away. Tum, the nearest town, has two diesel networks which are in operation and provide partial service to government buildings and commercial facilities like hotels and shops during the day and evening hours. Maji village has also an old 27 horsepower (hp) diesel generator which is used as micro-grid for about twenty-two rental households, this diesel generator was previously used as a grain miller (NRECA International, 2017).

As per Ethiopian government's national electrification program 2 (NEP 2) classification since Maji's proximity to the national grid line is beyond 25 km, it is categorized as a long-term pre-electrification/off-grid households' group. As per the NEP, these households will not be connected to the national grid by 2030 (USAID, 2019).

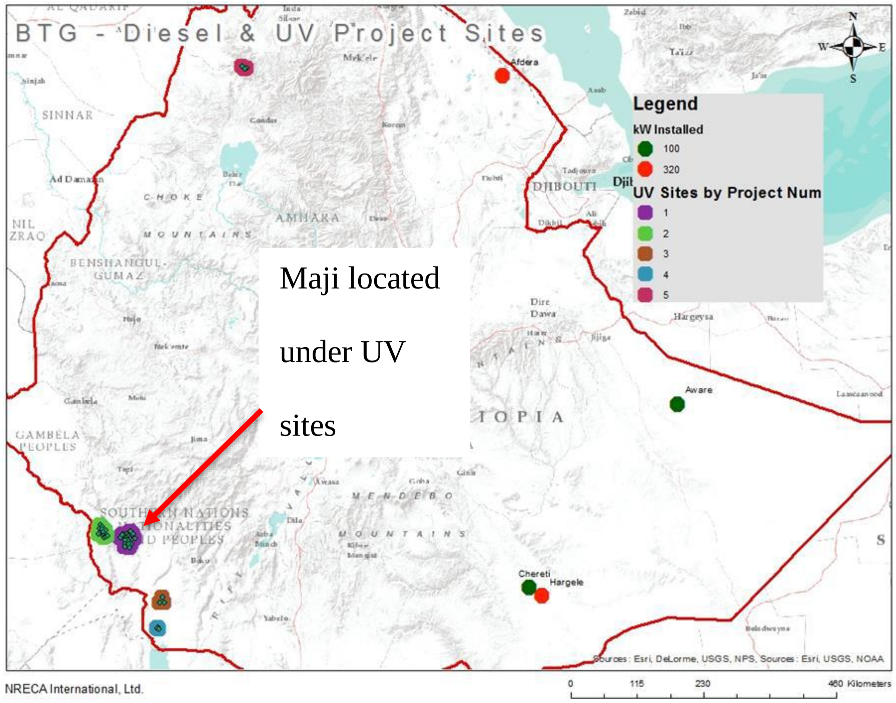


Figure 2. 2 UV (unelectrified villages) areas (NRECA International, 2017)

According to a base line study developed by EECMY DASSC (2017) the majority of households in Maji (95%) have no electric light at their homes and hence use fuel wood and kerosene for power, only a few (5%) have light from a solar panel and diesel generator network rental.

NRECA International is one of the major stakeholders for Maji off-grid solar energy project providing technical advice and completed a feasibility study report funded by USAID in 2017 to examine four existing EEU managed diesel mini-grid sites and five clusters of un-electrified (UV) villages in which Maji is one of the five clusters designated as UV. The aim of this report was to establish a framework for private investment in “beyond the grid” communities throughout Ethiopia. According to this report the forecasted annual energy consumption in Maji for a customer count of 916 households is 388,939 kWh (kilo-watthour) with a peak demand of 129 kW (kilowatt) which means the average energy consumption for a household in Maji is about 35 kwh/month or about 425 kwh/year, which is a small fraction of the typical energy consumption in the US of 877 kwh/month or 10,469 kwh/year. The Levelized Cost of Electricity (LCOE) which is calculated by evaluating the total annual cost of generation divided by the annual (kwh) consumption, LCOE is total cost of generating the electricity per unit of electricity delivered to the mini-grid customers. The report used HOMER Pro (a software simulation tool used to develop and evaluate electrical generation options based on forecasted electrical energy demand). The report considers two centralized power generation and distribution system options: solar-diesel hybrid systems and solar-battery-systems, and the result shows if Maji implements a solar-diesel hybrid system the project will require a capital cost of $1,002,750 USD with an LCOE of $0.41 USD/kWh, However, if it is centralized solar-battery-system it will require a capital cost of about $2,366,750 USD with LCOE of $0.66 USD/kWh. However, as per the report, if a commercial approach with distribution component and need of clustering different villages together (different Kebeles of Maji) to achieve sufficient scale considered, it needs much higher capital cost of about $4.1 million USD (NRECA International, 2017).

In summary, the government's off-grid strategy NEP-2 shows a strategic plan for use of mixed off-grid energy solutions in which about 70% will be centralized solar hybrid mini-grid solutions for high energy consumption and productive use of energy for irrigation, electric cooking and agro-processing, and the remaining 30% is planned to use decentralized off-grid solar energy solutions such as solar home systems and standalone solar application for rural household use and small scale businesses. In addition to government activities there are several community managed off-grid solar energy projects which are supported by non-governmental institutions and international donors such as GIZ, USADF, SEF, and Plan International Ethiopia. The fact that there is no privately financed and owned off-grid solar energy project in Ethiopia shows the existence of barriers and unfavorable condition of making such investments. When we think of community based decentralized off-grid solar energy solutions for rural communities it should encompass at least the basic energy needs of the community which will not be solved by the distribution of solar lanterns and home systems alone. A rural community typically has at least one health post, schools, a water source, small scale business, and government offices which needs electricity in order to provide better services If we truly want to bring positive change to the community, we need to work on providing comprehensive solutions.

Parallel to EEU's effort to address access to electricity to off-grid communities, strong government support to private investors and community owned service providers will be key to achieve a high degree of quality service and active community engagement. Policies and regulations have to work on tackling financial constraints such as foreign currency, bank loans and subsidy issues, import procedures have to be clear and there must be consistent working environment among various regional government agencies.

2.2. Theory of change

Maji Decentralized Off-grid Solar Energy Project (MDOSEP) is already in the implementation phase and I prepared the theory of change with the aim to understand what assumptions and critical questions are facing the project at the moment and hence, to help re-evaluate and suggest possible solutions.

The intervention is to provide off-grid solar energy solutions mainly focused on household use and productive use solar energy technologies for Maji community. The assumptions were that the rural community will benefit from this technology by providing more income to the rural houses, women and children will have extra time to study, and rural community health outcomes will improve. The goal is to improve the socio-economic conditions of Maji community. In the theory of change many critical questions are raised but the main question is “can this rural off-grid solar energy project be sustainable.” The unexpected turn for the case of the Maji project is the fact that there is a serious foreign currency issue which is limiting the access to solar technologies and spare parts and bigger solar solutions for community services such as health facility and water pumping needs significant funding and subsidy. A possible intervention in the theory of change suggests that involving all stakeholders and improving local capacity is needed, and rethinking on how to access foreign currency through international funds (for example: The World Bank Fund though DBE) and revising the business model to see if the sales of solar home systems and other productive use of solar solution can cover some of the costs for the bigger energy needs to minimize the subsidy and funding requirement. The details of the theory of change are explained in Table 2.1 below

Table 2. 1 Theory of change

1- INTERVENTION	2- ASSUMPTION			3- GOAL
DECENTRALIZED OFF-GRID SOLAR ENERGY SOLUTIONS Rural house use  Productive use 	**RURAL HOUSE INCOME INCREASES**	**WOMEN AND CHILDREN USE EXTRA TIME TO STUDY AND SOCIALIZE**	**RURAL COMMUNITY HEALTH IMPROVES**	**IMPROVED SOCIO-ECONOMIC CONDITION OF RURAL COMMUNITY** 
CRITICAL QUESTION: **Can rural off-grid solar energy projects be sustainable?**	**CRITICAL QUESTION:** Can rural community have access to productive use solutions for income generating activities	**CRITICAL QUESTION:** Do women and children use extra time to study?	**CRITICAL QUESTION:** Does off-grid solar solutions improve rural health?	**CRITICAL QUESTION:** How to measure socio-economic improvement locally?
UNEXPECTED TURNS **Rural off-grid solar energy projects face access to equipment and spare parts due to foreign currency shortage; bigger energy demands such as: rural clinics and water pumping systems needs significant funding and subsidy.**	**UNEXPECTED TURNS** Rural people usually expect free gifts, and cannot afford to pay for productive use solutions	**UNEXPECTED TURNS** Women and children might be forced to do other family activities	**UNEXPECTED TURNS** Solar solutions for water pumping and health posts need big investment	**UNEXPECTED TURNS** Off-grid solar energy projects might affect other existing business activities related to Kerosene and diesel generator
POSSIBLE INTERVENTION: - **Collaboration between private business, government and non-government organizations** - **Local community participation** - **Local capacity building and training** - **Organized aftersales service**	**POSSIBLE INTERVENTION:** - Awareness creation - Credit facility with PAYGO solution - Organize women self-help groups	**POSSIBLE INTERVENTION:** Awareness creation about the value of education for women and children	**POSSIBLE INTERVENTION:** Raise fund through NGOs and development organizations	**POSSIBLE INTERVENTION:** - Involving people affected in the new project - Awareness creation about the negative impact of kerosene and diesel generators for the environment
RETHINK: Consider accessing international funds, and revise your business model to see if it is possible to cover some of the costs for larger energy demands through sales of solar home systems and productive use applications.	RETHINK: Provide subsidy for women self-help groups?	RETHINK: Work with local churches and influential peoples	RETHINK: Consider income generating and savings for after sales service	RETHINK: Refine the project goal?

2.3. Stakeholder analysis

MDOSEP identified key stakeholders and made sure they are all participated at different level of the project and they were identified as key, primary and secondary stakeholders shown in Table 2.2 below.

Table 2. 2 Stakeholder analysis

Stakeholders	Interest /influence in project	Project phase	Engagement approach	Engagement Frequency
Key stakeholders				
STT and MDC, SEF initiative	- Project developing - Financing - Import and distribution - Installation and training	All	personal meetings and e-mail exchange.	Very frequent
WSHGs (Women self-help groups)	- Direct beneficiary - Own IGA (income generating activity) - Provide solar home system and water dispensing to the community	Implementation	Focus group meetings	Frequent

Churches	- Organize WSHGs, awareness creation. - Involved in a base line study	All	Focus group meetings	Less frequent
Primary stakeholders				
Local community	- Direct beneficiary, as a user of off grid solar energy solutions	ALL	Focus group meetings	Less frequent
NRECA International	- Technology and strategy supporter to the project	Initial	consult	Less frequent
Secondary stakeholders				
Maji woreda water and energy bureau and health office	- Local resource allocation	ALL	consult	Frequent
Local technicians and laborers who will construct the systems	- employment, job creation	Implementation	Focus group meetings	Less frequent

2.4. Maji Decentralized Off-grid Solar Energy Project (MDOSEP)

This project has been initiated and planned by the Maji Development Coalition (MDC) a USA based non-profit organization. Caroline Kurtz is founder and Executive Director of MDC, her parents lived and worked in Ethiopia mostly in Maji for 23 years, she was with her parents in Ethiopia from the age of four until she married and went back to USA, she returned back to Ethiopia in 1990 and taught English to Ethiopian girls ages 4-8 and hence she considers Ethiopia as her home. Caroline realized the need for this project in 2015 when the Maji community requested solar light for the health post’s delivery room where about 18 women each month were giving birth at night by flashlight (MDC, 2020).

In 2018 MDC approached SEF and STT and established a memorandum of understanding to work on developing decentralized off-grid solar energy solution for the Maji community. Since then, a number of major milestones have been achieved.

- About 300 units of 20-watt and 50-watt solar home systems have been distributed and sold a subsidized cost to the various kebeles in Maji with PAYGO model with a 20% upfront payment and the rest with a three-year payment plan from 2019 to 2021 Figure 2.3 below shows STT’s activity in distribution and installation of solar home systems in Maji.

- 20-watt solar home system to power three lights, phone charging, radio
- 50-watt solar home system to power three lights, phone charging, and 24” TV

Figure 2. 3 Solar home systems distribution and installation in Maji.

- Women self-help groups received about 6 productive use solar phone charging stations in 2021 to help them generate their own income from cell-phone charging business. Figure 2.4 below shows some of the women receiving the solar phone charging box

Figure 2. 4 Women self-help groups getting productive solar use phone charging

- Figure 2.5 shows the 15.6 kilowatt Maji solar water pumping project completed in 2021, this system can supply about 80,000 liters of water per day from a borehole, it serves more than 5,000 people in Maji and is the only drinking water supply source for Maji community.


Figure 2. 5 Maji solar water pumping project

Figure 2.6 shows the 33.6 kilowatt solar power system installed for Maji Hospital in 2021, it is designed to supply power for laboratory equipment, office appliances and lighting for the entire hospital


Figure 2. 6 Solar power system installation at Maji hospital

2.5. Needs assessment

I have prepared two surveys as indicated in Annex A (a household survey and stakeholder survey) for the case study of decentralized off-grid solar energy solutions. The household survey was developed for Maji community members who bought solar home system solutions.

Both primary as well as secondary data and information were collected during the course of the study, investigation and observation. The household survey questions were intended to collect primary data through interviews, and analyze the relevance, efficiency, effectiveness, impact and sustainability of the solar home system installations in the rural community of Maji. The stakeholder survey questions are also intended to collect primary data from the CEO and owners of the companies (MDC, SEF and STT) who are directly involved in the planning, design, financing and implementation of the project. The stakeholder survey is intended to gather firsthand information about the challenges and opportunities in the planning and implementing of decentralized off-grid solar energy solution in the case for remote village of Maji community.

2.5.1. Sampling and sampling techniques

A simplified formula to calculate sample sizes. A 90% confidence level and margin of error *e* = 0.1 are assumed. (Adam, 2020).

$$n = \frac{N}{1+Ne^2} = \frac{\mathbf{300}}{\mathbf{1+300(0.1*0.1)}} = \textbf{75 end users}$$

Where: n = is the sample size,

N = is the population size

e =acceptable margin of error; was taken 10% (analysis is more to infer results in an exploratory manner)

Accordingly, interview has been contacted to 80 Maji community solar home systems end users which are randomly selected from different Kebeles based on a mix of 20 watt and 50 watt system end users and location of the Kebeles and interviewed as per the household questionnaires as shown in Figure 2.7 below. We conducted 80 samples instead of 75 to maximize the number of samples in case we miss some collected data.

Figure 2. 7 Conducting interview for survey-1 questions at different rural houses in Maji

2.6. Survey Analysis and Results

2.6.1. Stakeholder survey

2.6.1.1. Policy and regulation

According to the results of the survey questions gathered from the CEO of the companies that are directly involved in the planning, design, financing and implementation of Maji Decentralized Off-grid Solar Energy Project (MDOSEP), Ethiopia's policy and regulation have not been clear or easy during the process of implementing this project. For example, in 2019 during the process of importing solar lanterns and solar home systems, suddenly we were asked to pay high duty and related taxes by customs, and their main reason were because the solar home system includes a solar TV, and the solar lanterns are made to be charged by an AC source too. Customs changed its regulation several times and there is no clear information flow in advance between importers and the responsible governmental entities. "The sudden imposition of high tax had many problems in the financial planning" according to MDC's CEO Mrs. Caroline Kurtz (C. Kurtz, personal communication, June 7, 2021) Both SEF's and STT's management also agreed that the inconsistency on taxing solar products is mainly because there is no clear guidance on how to apply the tax regulations, customs officers have difficulty when it comes to identifying the various solar product components at customs level. There is also no clear guidance on how obtain tax exemptions on solar products due to inconsistent requirements of third-party quality certifications.

2.6.1.2. Financial constraints

The survey results also indicated that this project has faced many financial challenges. The MDC CEO Mrs. Caroline stated that (C. Kurtz, personal communication, June 7, 2021), "*One of the most serious financial challenges has been at the fault of the global financial system, which puts countries like Ethiopia at a severe disadvantage in needing hard currency in order to purchase equipment on the global market. However, government policies have made it harder by not allowing an organization in Ethiopia to receive grants or payment in dollars without going into the banking system and being converted to ETB (which then is not available to the recipient NGO to order equipment)*"

Ethiopia's financial system doesn't have consistent regulation for easy access to foreign currency at local banks. Though the project has managed some importations through STT using its own USD retention account, due to lack of support from banks the importing process was not smooth as described by STT management in the questionnaire. However, foreign currency for lanterns and solar home systems importation was available with the help of World Bank through Development Bank of Ethiopia (DBE). However, importation through DBE was only allowed for lanterns and small solar home systems, and the process was complicated and it requires collateral and guarantee with up to 12.5% interest rate which is difficult for small scale private companies like STT to access. For a project like MDOSEP, it requires importing a range of off-grid solar energy solution beyond solar lanterns and home systems.

SEF's CEO Mr. Samson told us (T. Samson, Personal communication, June 6, 2021 that most of the funds for this project were secured through donation from MDC, however, accessing the foregoing currency for private companies through local banks for importation to supply the solar solution in a sustainable manner is very difficult because the local banks have no clear regulation from the National Bank of Ethiopia (NBE) to allow access to the foreign currency in a regular bases as describe by MDC's CEO too.

The project is providing solar home systems to Maji community on three-years credit with PAYGO model, and the survey result also showed us that out of the 300 solar home systems distributed so far 23.3% of them were sold using 100% cash sales and the remaining 76.7% sold using credit. However, MDC's CEO Mrs. Caroline stated that (C. Kurtz, personal communication, June 7, 2021) "*We allowed people to pay over a three-year period, with a lease-to-own contract, that has made it more complicated and costly. MDC have had to carry the PAYGO agreement and pay for it over three years and collection has made work for the office staff. We can afford to have and pay the staff, so that is not a big problem. Carrying the PAYGO cost for three years makes it less sustainable and increases the need for more USD*" This situation was created mainly because the payment collection is in local currency which becomes unpredictable and unstable (for example in the past three years alone the Birr devaluated more than 60% against USD) which is hard to forecast and impose the maximum exchange rate on the end user.

Rural end users' PAYGO payment for solar solutions through mobile phone is so far not applicable in remote areas like Maji community, however the recent launch of Ethiopian telecom service "telebirr" in 2021 is believed to enable mobile payment service accessible in most rural communities like Maji soon, which will ease the payment collection workload of the MDC staff.

2.6.1.3. Technical

According to the survey results the main technical challenges for this project are the availability of spare parts like solar batteries and solar TV components, with limited foreign currency access importing products and spare parts in timely manners is still a challenge.

2.6.1.4. Networking

MDC's CEO explained that even though there is limited communication and support from the federal government offices, government agencies at the regional level particularly Maji Woreda (Maji woreda water and energy bureau and health office) have been very collaborative for this project. They were able to share some of the costs from government budgets for part of the big solar systems that the project installed in Maji including the solar water pumping and solar hospital systems.

2.6.1.5. Socio-cultural

One of the questions in the survey was to determine if Maji community members participated in the project planning, implementation and evaluation process. According to the survey results an initial Maji community focus group discussion had been completed. MDC's CEO told us that (C. Kurtz, personal communication, June 7, 2021) an informal survey has been conducted in several neighborhoods to understand their household energy demand in terms of number of lights, phone charging, or any needs to add appliances like radio and TV. The local church in Maji was one the key stakeholder to provide this baseline survey to understand the local socio-economic condition, help to create awareness about the project, and to support women to be part of the project. The focus group discussion was important to estimate how much an individual household can afford for the several options provided, some of the discussion events happened in Maji is shown on Figure 2.8.

Figure 2. 8 Focus group discussion with Maji community members with product demonstration

MDC's CEO also explained that at first distribution of the solar lighting system were slow because people in Maji did not accept the idea of making advance payments with the PAYGO credits system. There was a cultural challenge as some people tend to want to try it out first and see if the solar system would work before deciding to pay in advance. However, after some community members demonstrated that the solar home systems were very useful for their families' others become interested in obtaining the solar home systems as soon as possible.

The importance of the solar home lighting for the Maji community as, Mrs. Caroline explained was that children can study at night, women have extra time due to the relief from burden of wood gathering which has also financial and environmental benefits, termination of buying costly dry cell batteries and kerosene which avoids pollution and smoke at homes.

Ms. Caroline also explained in the questionnaire that her NGO is helping the poorest of the women in the community to organize themselves and engage in income generating activities by donating 10-watt peak solar phone charging kits as shown in Figure 2.9 below. These women are using the solar charging kit to provide cellphone charging services to the neighborhood, which is a source of additional income for themselves.

Figure 2. 9 solar phone charging demonstration for Maji women

2.6.2. Household survey

The case study also includes survey questionnaire for Maji households for those who bought solar home systems from the project. Data was collected from 80 randomly selected end users through interview, the survey result is analyzed based on the categories stated in the questionnaire.

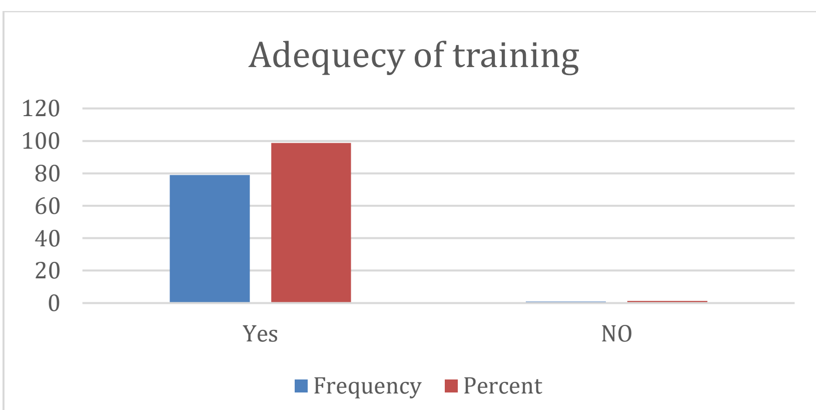
2.6.2.1. Training and knowledge transfer to the end user

The project provided end user training to all solar home system users during installation. Training was given to the husband and/or wife or to any family member who is responsible and old enough to understand the training materials. The training is intended to give basic knowledge to the end users on how to use the solar home system, what to do, and what to not to do to properly use and maintain the systems for example during installation end users are advised to check the solar panel every week or in two three weeks if it is dusty or have any birds drop or leaves that create a shadow, and hence they have to clean it accordingly. However, the cleaning frequency depends on the house location, those house with dusty area close to gravel roads needs frequent checkup (probably every week).

An end user manual is given to each household which shows how to use the solar home system. According to the survey results, out of 80 randomly selected users 79 of them (98.8%) said they received training during installation and it was adequate and only one person (1.2%) said the training was not adequate. These results are summarized in Table 2.3 below.

Table 2. 3 Analysis on adequacy of training

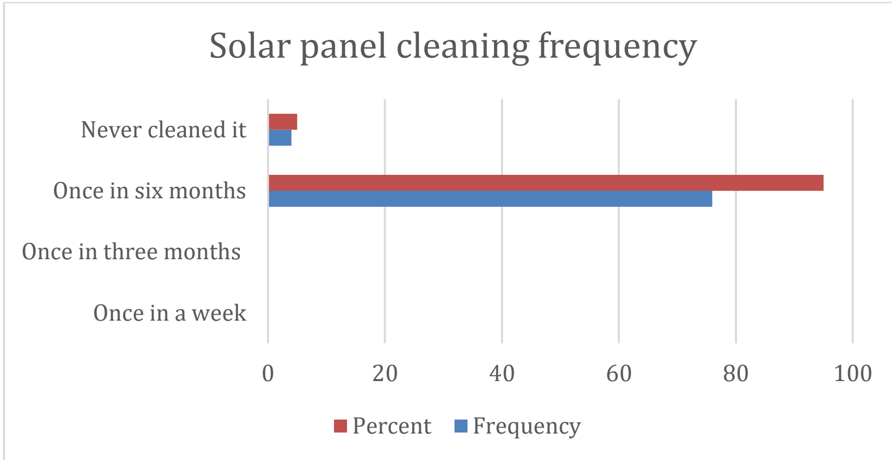
Adequacy	Frequency	Percent
Yes	79	98.75
NO	1	1.25
Total	80	100



However, the survey results also showed that the solar home system users are not fully applying what they learned in the training. The survey results indicated that 95% of respondents indicated that they were cleaning the solar panel every six months and 5% reported that they have never cleaned it. None (0%) of the respondents reported cleaning the solar panel once a week or once every three months. These results are summarized in Table 2.4 below. Therefore, even though training was given at the time of installation to the end users to clean the solar panels, a significant number of people are not cleaning them frequently, which shows that it needs every stakeholder needs to promote and increase awareness of the importance of cleaning the solar panels to ensure maximum power generation. The project needs to improve its operation by doing frequent visit to rural houses and conduct re-training the end users to do the cleaning more frequently. Particular attention should be given to those rural houses close to the main gravel roads as they are most likely having more dusty condition. The project needs to consider having a remote monitoring system for the solar home systems, such systems are important to remotely check if the solar system charge and discharge scenario is normal, and hence, advise the end user to clean the panel and/or manage energy use, such system will minimize the need to frequent travel to the rural house and prevent system failures in advance.

Table 2. 4 Analysis of solar panel cleaning frequency by the users

Solar panel cleaning frequency	Frequency	Percent
Once in a week	0	0
Once in three months	0	0
Once in six months	76	95
Never cleaned it	4	5
Total	91	100



2.6.2.2. Preference on the product range

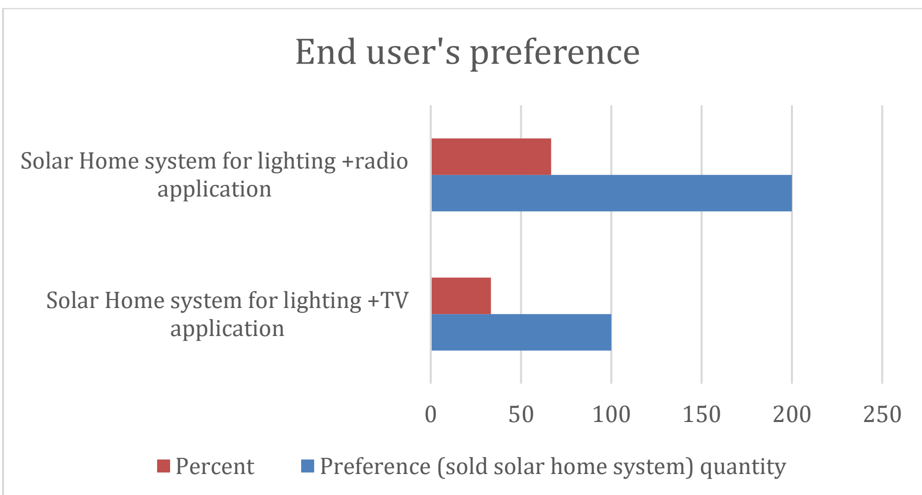
Based on past experience and the initial needs assessment, the project was able to provide two solar home system types based on their capacity:

1. 50 watt-peak solar home system for lighting, cell phone charging, and TV appliances
2. 20 watt-peak solar home system for lighting, cell phone charging, radio appliances

The survey results showed that the main factor for the users to decide on the type of solar home system was their financial capacity to afford the system they want to buy. Most of the Maji households prefer to have the smaller solar home system for lighting, phone charging and radio as described on Table 2.5 below. The satisfaction level analysis below also shows less interest to SHS with TV, and it as mainly because most customers who bought the SHS with TV tend to overuse the system which has led to depletion of the battery quickly, and some have claimed their defective TVs were not maintained or fixed quickly; and hence, interest in the community to have SHSs with TV has been reduced.

Table 2. 5 User's preference on the application of solar home systems

S/N	Type of application	Preference (sold solar home system) quantity	Percent
1	Solar Home system for lighting +TV application	100	33.33
2	Solar Home system for lighting +radio application	200	66.67
	Total	300	100

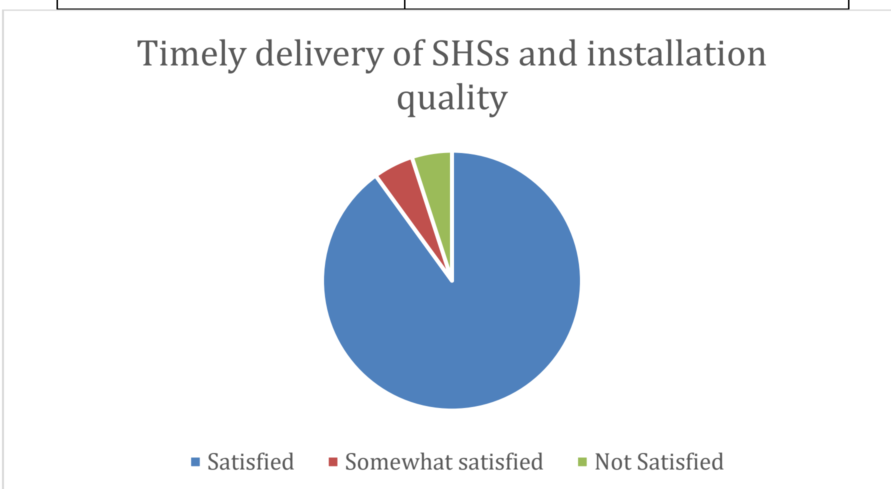


2.6.2.3. Measure of satisfaction of the solar home system services

The effectiveness in the installation of solar home system can be measured in terms of delivery time and installation quality. According to the survey results, 90% of respondents said that they were satisfied with satisfaction as to whether the solar home system was delivered in a timely manner and with a quality installation, while 5% said they are somewhat satisfied, and the remaining 5% not satisfied because they had their system installed too late and some of the systems with TV had repeated technical issues as shown on Table 2.6 below.

Table 2. 6 Satisfaction level on delivery time and quality of installation

Satisfaction level	Timely delivery of SHSs and installation quality
Satisfied	90
Somewhat satisfied	5
Not Satisfied	5
Total	100



The satisfaction level of the solar home system users due to this project is also measured based on the functionality of the solar home system to the end user for the intended application. Therefore, end users were asked for their satisfaction level for the installed solar home system in terms of use and functionality, the result shows as described on Table 2.7, the vast majority is satisfied with both type of solar home systems. Figure 2.10 below shows a family in Maji enjoying a 50 Wp solar TV system, however, a relatively higher number of end users who purchased a 50 Wp solar home system with lighting, phone charging, and TV were not satisfied. The main reason for the dissatisfaction in 50 Wp system was because they said their TV had some technical problems. As per the explanation given from the technical people from the project team most end users tend to watch TVs beyond the designed usage hours per day, and hence they overuse the system which damages its battery quickly. Some end user also expressed their concern regarding technical issues with the TVs and people from the project team told us that they are aware of the issues and are providing aftersales service accordingly.

Table 2. 7 Satisfaction level by the functionality of solar home systems

Satisfaction level	**Solar home system functionality for lighting, phone charging and radio (percent)**	**Number of respondents**	**Solar home system functionality for lighting, phone charging and TV (percent)**	**Number of respondents**
Satisfied	97.5	78	90	72
Somehow satisfied	2.5	2	3.75	3
Not satisfied	0	0	6.25	5
Total	100	80	100	80

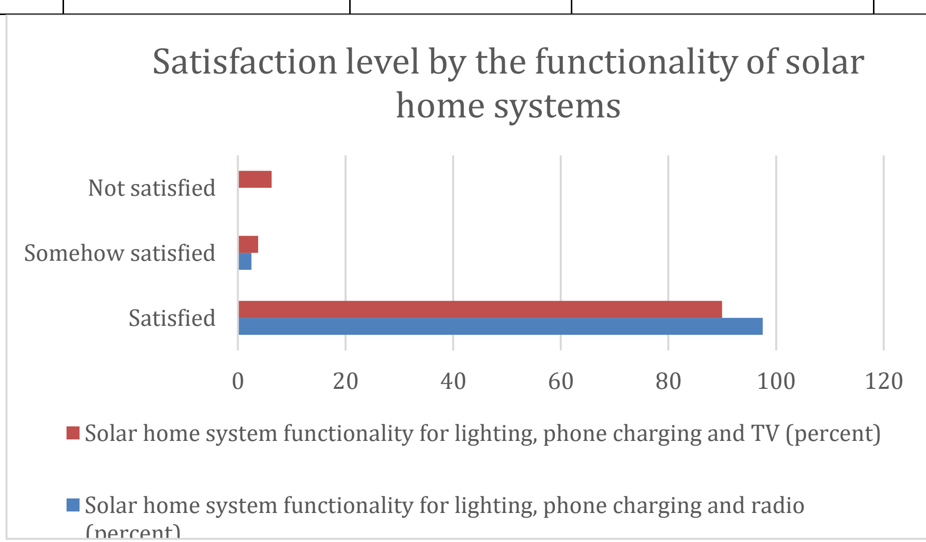


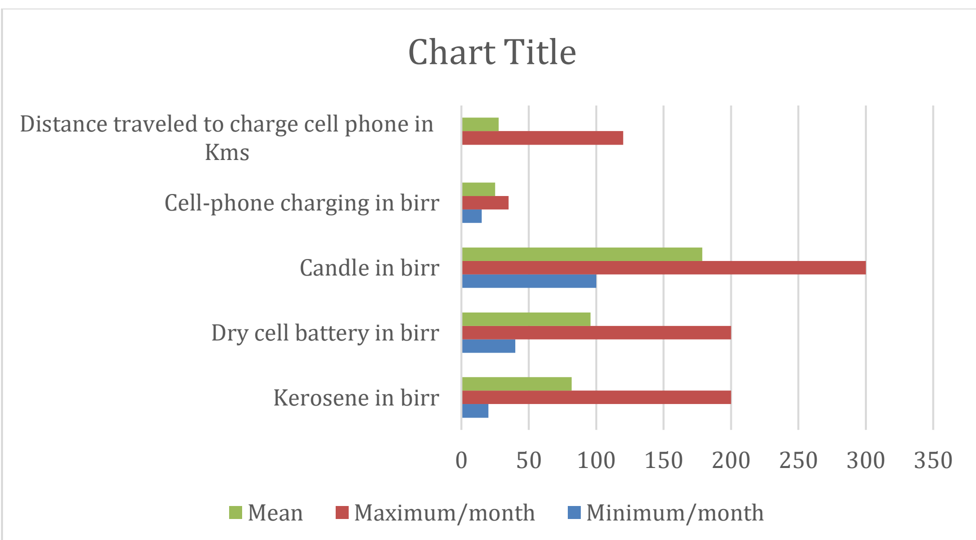
Figure 2. 10 Rural house family in Maji enjoying their 50 wp SHS with lighting and solar TV

2.6.2.4. Financial benefits

The survey results also show the Maji household expenditures for traditional energy sources that has been spent before the project starts. The randomly selected respondents were asked their estimated expenditures for energy sources such as: kerosene, dry cell batteries, and candles which were used prior to the purchase of the SHS. The respondents were also asked what distance they were traveling to charge their cellphone. The data collected indicated that they used to spend most of their energy expenditures for dry cell batteries and kerosene with an average monthly expenditure of birr 95.7 (2.2 USD) and birr 81.79 (1.9 USD) respectively. Most of the respondents said they were not using candles as they are very expensive. The smallest expenditure was for cellphone charging with an average monthly expenditure of birr 25 (0.57 USD). However, people in Maji were traveling average 27.6 km and for some of them up to 120 km in one month to get their cell phone charged at the nearby villages as shown in Table 2.8 below. The analysis also showed that the total energy expenditure per month for a single household was about birr 220 (5 USD) and from the data collected one can concluded that a rural household in Maji was spending birr 2610 (60 USD) per year. Total cost of a 20Wp solar home system that can power three lights, phone charging and with radio is about birr 7,000 (161 USD) which lasts at least 5 years without any running cost, which means a rural household in Maji is saving at least 50% of its previous expenditure per year and getting a clean energy source from solar at the same time.

Table 2. 8 Estimated household energy expenditure month/Birr

Category	**Minimum/month (birr)**	**Maximum/month (birr)**	**Mean (birr)**
Kerosene	20	200	81.79
Dry cell battery	40	200	95.7
Candle	100	300	178.6
Cell-phone charging	15	35	25
Distance traveled to charge cell phone in Kms	0.6	120	27.6



2.7. Summary of the case study

Maji community which is an area designated as an off-grid area by Ethiopian Electric Utility until 2030 needs alternative energy sources to bring its households out of energy poverty. Literature showed us that a centralized solar off-grid energy solution will cost up to 4 million USD, however, the Maji Decentralized Off-grid Solar Energy Project (MDOSEP), has shown that it is possible to address the energy access issues of the community little by little using decentralized solar solutions which have proven to be cost effective compared to the centralized system as per the NRECA (2017) report if a central system like a solar mini-grid (or solar mini-grid with diesel hybrid system) is to be implemented in Maji as a commercial approach with distribution component and clustering different villages together is required it needs capital cost of about $4.1 million USD. However, so far, MDOSEP has spent only about 220,000.00 USD and the project managers believe it is possible to address more rural villages energy need in Maji with a reasonable amount of project cost (estimated cost to provide additional 1500 units of 20Wp SHSs and 500 units of 50Wp SHSs and additional 10 productive use solar solutions to rural clinics, schools, offices and business for Maji community will be about $1 million USD). However, the project has also faced challenges due to policies and regulations which are seen at federal governmental agencies like customs in tax issues, and banks which have shortage of foreign currency which delays products and spare parts access. However, the project is still working with various stakeholder to address some of the challenges; for example, the project started with participation from the local government agencies like Maji Woreda, and they were convinced about the importance of the project for Maji community. The project so far has been able to distribute more than 300 solar home systems to the rural houses, Maji community drinking water supply has been 100% powered by a 15.6 kilowatt solar water pumping system, and the Maji hospital was 100% powered with a 33.3 kilo watt solar power system.

Some of the facts in comparing the literature with the case study were; the literature shows there is inconsistent tax regulations at customs, in Maji project we saw also importing the solar home systems were facing high taxations. Literature also shows there is no consistent working environment between federal and regional energy agencies, and the survey also shows that there was limited cooperation at federal level. Many studies in the literature shows there is series foreign currency shortage in the country, and the survey also revealed that Maji project has faced foreign currency challenge. Many off-grid solar energy projects don’t involve communities as per the literature, but the survey shows Maji project conducted focus group discussions and shows positive progress in engaging women self-help groups. Literature shows off-grid solar energy solutions have many benefits for rural communities, the survey result also shows, SHSs in Maji has high level of satisfaction and it was also cost effective for the community compared to the traditional energy sources.

3. Conclusion

This capstone paper used a case study called Maji Decentralized Off-grid Solar Energy Project to analyze the sustainability of developing solar powered electricity for rural communities in Ethiopia, primary data through interviews and secondary data from literature review were collected and analyzed to see the barriers and then to suggest possible solutions. The main challenges in developing and implementation of off-grid solar energy solution for rural communities in Ethiopia were inconsistent implementation of policies and regulations at different government offices, lack of coordination and integration between private companies, NGOs and government entities. The other major challenge was shortage of foreign currency which limits the availability of solar energy solutions and increased the cost of products in the local market. Rural households have little financial capacity and hence in most cases cannot afford to pay in advance for off-grid solar energy solutions unless there is long term credit facility. Limited technical capacity to provide installations and after sales service due to lack of organized and country wide training facilities on solar energy is also one of the challenges. Finally, most rural off-grid solar energy projects lack community participation in every phase such as in design, development, implementation, and evaluation.

Most off-grid solar energy projects have been implemented through international development organizations, however the Ethiopian government is also improving its policies and regulation by providing programs and strategies to address the off-grid energy issues. The government has indicated that solar energy solution one important focus area, but most of the government's efforts are towards connecting more rural cities to the national grid, and the off-grid areas are largely left for the private sector to explore. On the other hand, most, private companies don’t have the capacity by themselves to provide solutions that have a package of decentralized off-grid solar energy solutions such as solar home systems; productive use of solar energy; and systems for schools, health centers, and water access which are key for a rural community. The case study indicated that if there is collaboration between various stakeholders like the private company, international and local NGOs, and federal and regional government agencies then it is possible to be effective in providing off-grid solar energy solutions for rural communities in Ethiopia. The Maji project has shown that solar home systems as one part of the off-grid solar energy solution were affordable and efficient because payment with installment is provided with a PAYGO model, and the project was also able to provided solar water pumping and a solar system for Maji hospital to address the real energy access challenge in the community. Further collaboration with international organizations like Solar Sister, IEEE Smart Village, NRECA International and others is recommended that would improve Maji project to scale up and address some the financial and technical and social challenges seen in the case study. Further technical and financial feasibility study and analysis are recommended to provide commercially feasible solar solution to the most important business in Maji town such as diesel run grain mills, metal and wood workshops. Small holder farmers can get small scale solar water pumping system for irrigation on credit bases using PAYGO model, however, feasibility of PAYGO for solar grain milling needs to be addressed with further studies

4. Recommendation for further studies

This capstone paper is more focused on challenges related to dissemination of decentralized off-grid solar energy solution for rural communities in Ethiopia, challenges related to centralized off-grid energy solutions such as solar mini-grids were not addressed in this paper mainly due to limited practical experience in the country, continued studies and analyses are also required to see the development of decentralized off-grid solar energy solutions as the population Maji increases, and its impact to women self-help groups. Finally further studies are needed to see the feasibility to the conversion of diesel run grain mills to solar grain mills based on Maji community's socio-economic condition.

References

Adam, A. M. (2020). Sample Size Determination in Survey Research. *ournal of Scientific Research & Reports*, 90-97. Retrieved from https://journaljsrr.com/index.php/JSRR/article/view/30263.

Adenle, A. A. (2020). Assessment of solar energy technologies in Africa-opportunities and challenges in meeting the 2030 agenda and sustainable development goals. *Elsevier*, 137, 111180.

Africa Clean Energy Technical Assistance Facility. (2021). *Stand Alone Solar (SAS), Market Up date, Ethiopia*. Nairobi: Tetra Tech International Development. Retrieved from https://sun-connect-news.org/fileadmin/DATEIEN/Dateien/New/Stand-Alone-Solar-SAS-Market-Update-Ethiopia.pdf.

Agsol Solar-Powered Mill. (2021). *Engineering for change*. From Agsol Solar-Powered Mill: https://www.engineeringforchange.org/solutions/product/agsol-solar-powered-mill/

Balasubramanian, S., Clare, D., & Ko, S. (2020). *Off-Grid Solar E-Waste: Impacts & Solutions in East Africa.* Durham: Duke University Master of Environmental Management.

Boamah, F. (2020). Desirable or debatable? Putting Africa's decentralised solar energy futures in. *ELSEVIER, Energy Research & Social Science*, 62 (2020) 101390.

Borgstein, E., Mekonnen, D., & Wade, K. (2020). *Capturing the Productive Use Dividend, Valuing the Synergies between Rural Electrification and Smallholder Agriculture in Ethiopia.* Rocky Mountain Institute. Retrieved from http://www.rmi.org/insight/ethiopia-productive-use/.

Cross, J., & Murray, D. (2018). The afterlives of solar power: Waste and repair off the grid in Kenya. *ScienceDirect*, 100-109. From Dukespace.

Daniel, S., Steurer, E., & Wagemann, B. (2017). Productive use of renewable energy supporting applied entrepreneurship-Lessons learned from a development project in rural Ethiopia. *Universities, Entrepreneurship and Enterprise Development in Africa. Retrieved from*, 7-24.

Ecofys & SNV Ethiopia. (2016). *'Off-grid Rural electrification in Ethiopia' NAMA developed within the Mitigation Momentum project.* Cologne: SNV, ECOFYS.

EECMY DASSC. (2017). *MAJI WOREDA BASE LINE STUDY.* MIZAN AMAN: Commissioned by Maji Development Coalition .

El Bassam, N. (2021). Solar energy: Technologies and options. In Distributed Renewable Energies for Off-Grid Communities. *Elsevier*, 123-147.

EMA. (2020, March 15). *Energy Market Accelerator Ethiopia* . From EMA: https://www.etoffgrid.org/2020/03/19/emas-lessons-from-india-solar-productive-use/

Energy and Economic Growth. (2020, September). *Improving productive uses of electricity in Ethiopia's agriculture*. From Energy and Economic Growth : https://energyeconomicgrowth.org/node/223

energypedia. (2018, 11 13). *energypedia.info*. From Productive Use of Electricity: https://energypedia.info/wiki/Productive_Use_of_Electricity#Defining_Productive_Use_of_Electricity

G. Gebreslassie, M. (2019). Development and manufacturing of solar and wind energy technologies in Ethiopia: Challenges and policy implications. *Renewable Energy*, 168 (2021) 107e118.

Geremew, Y. M., & Hailemeriam, L. Y. (2015). Site Suitability Evaluation of Ecotourism Potentials for Sustainable Natural Resource Management and Community Based Ecotourism Development. *Scholars Journal of Arts, Humanities and Social Sciences. Retrieved from https://www.academia.edu/attachments/44063568/download_file?st=MTYzMDMyMjA4NiwxOTYuMTg4LjExNy4xMDU%3D&s=swp-splash-paper-cover*, 1368-1383.

GOGLA. (2018a). *Powering Opportunity The Economic Impact of Off-Grid Solar. Retrieved from https://www.gogla.org/sites/default/files/resource_docs/gogla_powering_opportunity_report.pdf.* Utrecht: UKaid.

GOGLA. (2018b). *Productive use of offgrid solar: appliances and solar water pumps as drivers of growth. Retrieved from https://www.gogla.org/sites/default/files/resource_docs/gogla_pb_use-of-off-grid-solar_def.pdf.* Utrecht: GIZ.

Gordon, E. (2018). The Politics of Renewable Energy in East Africa. *THE OXFORD INISTITUTE FOR ENERGY STUDIES*.

Hussen, E. (2018). Causes of Deforestation in Benchi Maji Zone, Shay Bench Woreda SNNPR, Ethiopia. *Doctoral dissertation, ASTU. Retrived from http://etd.astu.edu.et/handle/123456789/1299*, 67.

IEA. (2019, November). *Africa Energy Outlook*. From IEA, Paris: https://www.iea.org/reports/africa-energy-outlook-2019

IEA. (2019, November). *Ethiopian Energy Outlook-Analysis*. From IEA, Paris: https://www.iea.org/articles/ethiopia-energy-outlook

IEA. (2020, October 12). *Change in global electricity generation by source and scenario, 2000-2040*. From IEA, Paris: https://www.iea.org/data-and-statistics/charts/change-in-global-electricity-generation-by-source-and-scenario-2000-2040-2

IEA. (2020, October 12). *Population without access to electricity by country in Africa*. From IEA: https://www.iea.org/data-and-statistics/charts/population-without-access-to-electricity-by-country-in-africa-2020

IEA Africa. (2019). *Africa Energy Outlook 2019.* Paris: IEA, from https://www.iea.org/reports/africa-energy-outlook-2019.

IEEE Smart Village . (2021). *About IEEE Smart Village*. From IEEE Smart Village: https://smartvillage.ieee.org/about-ieee-smart-village/

IRENA. (2015). *Roadmap for a Renewable Energy Future. IRENA.* Abu Dhabi: IRENA from www.irena.org/remap.

Joshi, L., Choudhary, D., Kumar, P., Venkateswaran, J., & Solanki, C. S. (2019). Does involvement of local community ensure sustained energy access? A critical review of a solar PV technology intervention in rural India. *Elsevier*, 122 (2019) 272–281.

kassa, G., Mekonnen, G., & Woldesenbet, M. (2018). Assessment of Weed Flora Composition in Arable Fields of Bench Maji, Keffa and Sheka Zones, South West Ethiopia. *Agricultural Research & Technology: Open Aaccess Journal*.

Khan, I. (2020). Impacts of energy decentralization viewed through the lens of the energy. *Renewable and Sustainable Energy Reviews, ELSEVIER*, 119, 109576.

Lakew, H., Hailu, B., Hailu, T., & Carter, S. (2017). *A climate for solar power: Solutions for Ethiopia's energy poverty*. Climate & Development Knowledge Network. Retrieved from https://www.africaportal.org/publications/climate-solar-power-solutions-ethiopias-energy-poverty/.

Lighting Africa. (2020, July 24). *Ethiopia*. From Lighting Africa, catalyzing markets for modern off-grid energy: https://www.lightingafrica.org/country/ethiopia/

MDC. (2020). *Maji*. From Maji Development Coalition: https://developmaji.org/get-to-know-us/history/maji-development-coalition/

MOWIE. (2019). *National Electrification Program 2.0.* Addis Ababa: Minitry of Water, Irrigation, and Energy. Retrieved from https://www.powermag.com/wp-content/uploads/2020/08/ethiopia-national-electrification-program.pdf.

MOWIE. (2021a, April 30). *Ministry of Water, Irrigation and Electricity.* From Energy Sector/Electric Utility: http://mowie.gov.et/alternative-energy-technology

Mugisha, J., Ratemo, M. A., Keza, B. C., & Kahveci, H. (2021). Assessing the opportunities and challenges facing the development of off-grid solar systems in Eastern Africa: The cases of Kenya, Ethiopia,. *Elseveier*, 150, 112131.

NASA . (2020). *NASA earth observatory*. From Plugging-in Sub-Saharan Africa. Retrieved from: https://earthobservatory.nasa.gov/images/148069/plugging-in-sub-saharan-africa

NRECA International. (2017). *Feasibility Study Report, USAID ETHIOPIA - BEYOND THE GRID (BTG).* Addis Ababa: USAID.

Oluoch, S., Lal, P., Susaeta, A., & Vedwan, N. (2020). Assessment of public awareness, acceptance and attitudes towards renewable energy in Kenya. *Scientific African*, 9,e00512. Retrieved from https://www.sciencedirect.com/science/article/pii/S2468227620302507.

Pappis, I., Sahlberg, A., Walle, T., Broad, O., Eludoyin, E., Howells, M., & Usher, W. (2021). Influence of Electrification Pathways in the Electricity Sector of Ethiopia-Policy Implications Linking Spatial Electrification Analysis and Medium to Long-Term Energy Planning. *Energies*, 14(4), 1209.

Pillot, B., Muselli, M., Poggi, P., & Dias, J. (2019). Historical trends in global energy policy and renewable power system issues in Sub-Saharan Africa: The case of solar PV. *Elsevier*, 127, 113-124.

Precise Consult. (2019). *Ethiopian Solar Energy Development Association Strategy.* Addis Ababa: Precise Consult.

Rahman, M., & Pokrant, B. (2014). Reflections on Working with Communities and Community-Based Projects in Bangladesh. . *Center for Natural Resource Studies, Springer, Singapore. Retrieved from https://link.springer.com/chapter/10.1007/978-981-4585-11-8_13*, 215-235.

Shanko, M., Hankins, M., Saini, A., & Kirai, P. (2009). *Ethiopia's Solar Energy Market.* Berlin: ResearchGate.

Sharma, R., Choudhary, D., Kumar, P., Venkateswaran, J., & Singh Solanki, C. (2019). Do solar study lamps help children study at night? Evidence from rural India. Retrieved from https://www.sciencedirect.com/science/article/pii/S0973082619301966. *Energy for Sustainable Development*, 50, 109-116.

SOLAR SISTER. (2018). *LIGHT HOPE OPPORTUNITY*. From SOLAR SISTER: https://solarsister.org/

SOLARGIS. (2020). *SOLARGIS*. From Download solar resource maps and GIS data for 200+ countries and regions. Retrieved from: https://solargis.com/maps-and-gis-data/download/world

Sun-Connect. (2013, April 11). *Carbon offset-project of the month: Solar Light for Rural Households in Ethiopia*. From Sun-Connect: https://www.sun-connect-news.org/news/details/carbon-offset-project-of-the-month-solar-light-for-rural-households-in-ethiopia/

Tariku, A. (2018). Inter-group conflicts in the horn of Africa: The case of Diz and Suri people, Ethiopia. *Human Affairs*, 28(2), 130.

Tetra Tech International. (2021). *AFRICA CLEAN ENERGY (ACE), TECHNICAL ASSITANCE FACILTY (TAF) Ethiopian Customs Handbook (Draft).* Addis Ababa: Tetra Tech International.

The World Bank. (2018, June). *Lighting Africa*. From Reaching out to Rural End-Users, Ethiopia: https://www.lightingafrica.org/country/ethiopia/

The World Bank. (2021a, 03 18). *The World Bank in Ethiopia*. From Wold Bank: https://www.worldbank.org/en/country/ethiopia/overview

The World Bank. (2021b, April). *Poverty & Equity Brief Africa Eastern & Southern Ethiopia*. From WORLD BANK GROUP Poverty and Equity: http://databank.worldbank.org/data/download/poverty/987B9C90-CB9F-4D93-AE8C-750588BF00QA/AM2020/Global_POVEQ_ETH.pdf

USAID. (2019). Off-Grid Solar Market Assessment Ethiopia. *USAID, Power Africa Off-grid Project*, 47.

van de Ven, G. W., Anne de, V., Marinus, W., Jager, I. d., Descheemaeker, K. K., Hekman, W., . . . Giller, K. E. (2020). Living income benchmarking of rural households in low-income. *Food Security*, 1-21.

Annex A

Household Survey

Topic

Decentralized solar home system pilot project in Bench Maji Zone, Maji Kebele

Target group

Rural households of solar home system (SHS) users in Maji Kebele. 300 Solar home systems 20Wp and 50Wp is already installed in Maji Kebele, minimum sample size will be 80 randomly selected end users.

Goal

To collect primary data through interview, and analyze the relevance, efficiency, effectiveness, impact and sustainability of the solar home system installations in the rural community in Maji kebele.

Location and demographic details of solar home system user

1. Woreda---------------------- Kebele--------------------, village -------------------------------
2. Respondent’s Name --
3. Representation in the family---
4. Education of the respondent
    1. Illiterate
    2. read/write
    3. priest
5. Family size (Total) --------------------- Male ---------------- Female ----------------------

End user training

6. Have your household members received training in relation to how to use the solar home system?
    1. Yes
    2. No

If your answer to question 6 is “Yes”, please proceed to the following questions from 7 to 10, if “No” skip to question 11.

7. Do you have a clear understanding of “what to do/not to do” about the system?
    1. Yes
    2. No
8. Who have got the training?
    1. Husband
    2. Wife
    3. Both husband and wife
    4. Other members of the household
9. Was the training adequate?
    1. Yes
    2. No
10. How frequent do you clean the solar panel?
    1. Once in a week,
    2. Once in 3 months
    3. Once in 6 months,
    4. Never cleaned it.

Satisfaction level in terms of SHSs reliable use and functionality

11. How satisfy are you with the time of solar home system delivery and installation?
    1. Satisfied
    2. Somewhat satisfied
    3. Not satisfied

If your answer is “Not satisfied” to question 12.

What was the reason? --

12. Which solar home system type did you buy?
    1. SHS for lighting and phone charging only
    2. SHS for radio, light, and phone charging
    3. SHS for TV, light, and phone charging
13. Why did you choose the specific type? --
14. Are you satisfied with the functionality of solar home system you bought?
    1. Satisfied
    2. Somewhat satisfied
    3. Not satisfied
15. Is there an increase in study hour of students in your house due to solar light?
    1. Yes
    2. No
16. How reliable is the solar home system use in terms of power output?
    1. Reliable

2. Neutral
3. Not reliable

17. If your answer to question 17 is “Not reliable” what was the reason? ------------------
18. In average how much money did you spend per month for traditional energy sources before you bought the solar home system

    For kerosene ----------------------------------

    For dry cell battery ---------------------------------

    For candle ---------------------------------

19. How far did you travel and how much did it cost to charge your cell phone? -------
20. Among the family, mainly whose task was to travel and buy kerosene, dry-cell battery or charge cellphone? ------------------------

Impact indicator

21. Has there been an improvement in health condition of the families because there is no kerosene lamp due to the SHS?
    1. Yes
    2. No
22. Has there been an increase in women’s engagement in productive and other household duties due to saving of time and energy that would have been lost in traveling to buy kerosene, dry cell battery or cell phone charging?
    1. Yes
    2. No
23. Do you think the project met its intended objective? If so, how? ------------------
24. What is your view on the sustainability and expansion of this project? ----------------

Stakeholder Survey

Topic

Decentralized off-grid solar energy solutions for remote villages of Maji community in Bench Maji Zone.

Target group

CEO of the companies who are directly involved in Maji off-grid solar energy project in the planning, implementation and evaluation of this project

Goal:

To understand the challenges of implementing decentralized off-grid solar energy solutions for Maji community

Policy and regulation

1. Is there clear federal and regional government policy and regulation for support of this project? If your answer is NO, please describe some of the main challenges you have observed

Financial constraints

2. What are the financial challenges of this project?
3. How many people in Maji bought the solar energy solutions 100% in cash?
4. How did you manage the affordability issues?

Technical

5. Is there any technical capacity challenge in this project in terms of system sizing, installation, after sales service, and infrastructure? If your answer is YES, please describe some of the challenges.

Networking

6. What is your comment on the communication and support from federal and regional responsible government offices for this project?

Socio-cultural

7. Does this project include Maji community members in the planning, implementation and evaluation process? If your answer YES, how did you engage community members in the project?
8. Is there any cultural challenge or benefit to this project?
9. In what way does the project support women?
10. What are the challenges of sustainability in the Maji decentralized off-grid solar energy project?
11. In what way is this project is working to tackle sustainability issues?