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Assessing Solar Energy Potential and Rigorously Analyze The Socio-Economic, Institutional, and Cultural Factors Affecting Adoption of Solar Energy Technology in Ziquala District, Amhara Region, Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF NATURAL RESOURCES MANAGEMENT

MSc PROGRAM

**ASSESSING SOLAR ENERGY POTENTIAL AND RIGOROUSLY ANALYZE
THE SOCIO-ECONOMIC, INSTITUTIONAL, AND CULTURAL FACTORS
AFFECTING ADOPTION OF SOLAR ENERGY TECHNOLOGY IN ZIQUALA
DISTRICT, AMHARA REGION, ETHIOPIA**

MSc Thesis

By

Agerie Fenta

May 2025

Bahir Dar, Ethiopia

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ETHIOPIA**

MSc Thesis

By

Agerie Fenta

**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of
Master of Science (M.Sc.) in “Environment and Climate Change”**

Advisor: Abebe Aschalew (PhD)

May, 2025

Bahir Dar, Ethiopia

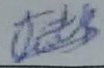
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THESIS APPROVAL SHEET

As members of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by miss **Agerie Fenta Asmare** entitled **"Assessing solar energy potential and rigorously analyze the socio-economic, institutional, and cultural factors affecting adoption of solar energy technology in Ziquala district, Amhara region, Ethiopia"**. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in **"Environment and Climate Change"**.

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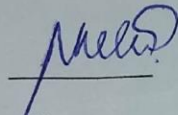
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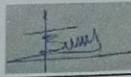
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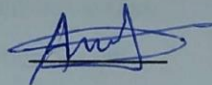


DECLARATION

This is to certify that this thesis entitled “Assessing solar energy potential and rigorously analyze the socio-economic, institutional, and cultural factors affecting adoption of solar energy technology in Ziquala district, Amhara region, Ethiopia” was submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in “**Environment and Climate Change**” to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by miss **Agerie Fenta Asmare** (ID. No. BDU1500029) is an authentic work carried out by him under our guidance. This thesis is my work and has not been presented for a degree in any other university or any other award.

Agerie Fenta Asmare

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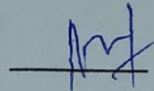
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DEDICATION

This thesis is devoted to my wonderful parents Fenta Asmare and Marie Tadele for their care, mediation, and constant support and motivation throughout my academic and personal journey. I wish long live for my parents.

LIST OF ABBREVIATIONS AND ACRONYMS

ANRS	Amhara National Regional State
CSA	Central Statistical Agency
DRC	Democratic Republic of Congo
EEP	Ethiopian Electric Power
EGP	Ethiopian green power
EMS	Ethiopian Metrological Service
FAO	Food and Agricultural Organization of the United Nation
FGD	Focus Group Discussion
FiT	Feed in Tariff
GERD	Grand Ethiopian Renaissance Dam
GIS	Geographic Information System
GPS	Geographic Positioning System
GSR	Global Solar Radiation
GW	Giga Watt
GWh	Giga Watt Hour
HH	Household Head
IDW	Inverse Distance Weighted
IEA	International Energy Agency
KII	Key Informants Interview
KWh	Kilowatt Hour
LED	Light Emitting Diode
LPG	Liquid Petroleum Gas
MBE	Mean Bias Error
MOWIE	Ministry of Water Irrigation and Electricity
MPE	Mean Percentage Error
MW	Mega Watt
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organization
PV	Photo Voltaic

REF	Renewable Energy Fund
RMSE	Root Mean Square Error
SDG	Sustainable Development Goal
SET	Solar Energy Technology
SHS	Solar Home System
SPSS	Statistical Package for Social Science
UNEP	United Nation Environmental Policy
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization
WMO	World Metrological Organization
ZWWEO	Ziquala Woreda Water and Energy Office

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ABSTRACT

Solar energy is one of the many benefits of renewable energy sources in many parts of the world including Ethiopia which also reduces energy costs and encourages energy security and environmental sustainability. This study aimed to assess solar energy potential based on sunshine hour record data and evaluate factors affecting the adoption of solar energy technology in Ziquala district. The data were collected from both primary and secondary data sources. First, the identified barriers are classified into economic, policy and institutional, information and human resource, technological, and societal, from various studies. The primary data was collected from household survey, questionnaire, key informant interview and direct field observation and focus group discussion with relevant experts, this thesis identifies the key barriers to the adoption of solar energy technology. The secondary data for the hour of sunshine for this station is collected from National meteorological agency in Eastern Amhara Kombolcha Center. The data used for the econometric model was collected from randomly selected 93 adopters and 256 non-adopters from three kebeles in Ziquala district. The data was analyzed using SPSS version 27 software to assess the level of solar energy technology adoption within the study area and tried to establish what gaps exist and why, provided for factors affecting adoption of solar energy technology, socio-economic implications of solar energy technology and effective strategies being used to raise awareness. Based on the Angstrom-equations the result of annual mean daily global solar radiation for three stations such as Tsitsqa, Lalibela and Amdework has 6.18, 5.69 and 5.75 kWh/m²/day respectively, which is actually very good solar energy potential and the statistical error test results in three station Mean bias error, mean percentage error (%) and root mean square error value has shown best prediction accuracy with the lowest value as a test of goodness of fit and the value has close to zero. This study concludes that policy measures should create awareness through training, education, information access and improving economic status of households to achieve enhanced adoption of solar energy technology. In this study Angstrom equation is highly recommended to estimate monthly average daily global radiation for the three stations.

Keyword: Adoption, Global solar radiation, Solar energy, Sunshine hour, Ziquala

CHAPTER 1. INTRODUCTION

1.1. Background and Justification

According to the International Energy Agency (IEA, 2020) report, over 700 million, more than half of Africans, lack access to electricity. Over 80% of the population in the Sub-Saharan region has no access to modern energy sources. Furthermore, Africa faces an electricity shortage which causes a number of power outages, and this phenomenon is worst in the sub-Saharan Africa region (Abotsi, 2016). For instance, more than 77% of sub-Saharan African firms experience frequent power outages, and the average number of power outages they experienced in 2020 in a typical month was over nine times (World Bank., 2021). The World Bank Group., (2015) stated that some reasons for repeated interruptions are due to having medium voltage conductors, interrupted lines or breaking, informal connections, and a high load of demand. The national energy policy encourages shifting the traditional energy usage (biomass) to modern and environmentally friendly energy sources. Access to energy services and renewable energy are increasingly acknowledged as prerequisites for sustainable development (Bhutto et al., 2019). Additionally, it helps to improve social fairness and supports green economic development as well as the delivery of useful services like health, education, communication, and drinking water (Mirzabaev et al., 2018). However, according to the Conti et al., (2016) about 1.3 billion people in the developing world lack access to electricity and as a result, many of them still burn kerosene to make light. Moreover, indoor air pollution (IAP) is linked to negative environmental and health effects when fossil fuels are used.

According to Fikremariam, (2014), energy is the primary commodity in the economy and the main economic artery of all nations. On the other hand, energy consumption also plays a part in environmental deterioration including soil degradation, air pollution, and sea level rise, and climate change. The usage of renewable energy can help with several important sustainable development goals (SDG), including fostering social and economic advancement, guaranteeing energy security, lowering environmental and health issues and mitigating climate change (Akinwale & Adepoju, 2019). Such a case applies not only to Ethiopia but also to most countries in Sub-Saharan Africa. Most live in the rural areas where there is no electricity and are therefore severely affected by the lack of access to renewable clean energy. According to Bensch et al., (2017), the government's recently launched National Electrification Program envisions

that by 2025, 65% of the population will be connected to the grid as they place a strong emphasis on scaling up connections in areas within short-term reach of the grid. A temperate off-grid solution will be

required by the remaining 35% of families, or around 7.7 million households the majorities of these households primarily use kerosene and spend about 4.5% of their total household consumption expenses on lighting. One of the major challenges facing developing countries such as Ethiopia to ensuring universal electricity access is the massive capital investment required to develop and expand grid infrastructures to off-grid (rural and remote) areas. For the bulk of Ethiopia's population lives in widely dispersed rural villages, studies have shown that providing conventional grid-electricity to most rural household is currently a costly undertaking for Ethiopia (Yibeltal & Adaramola, 2021). Even when Ethiopia's Grand National electrification program is completed, only 65% of the total population will have access to electricity by 2025. This means that the remaining 35% (12 million households mainly in rural/off-grid areas) will still be living without electricity (Hilawe *et al.*, 2017). In Ethiopia solar PV is utilized for off-grid areas and grid connected areas. Solar PV for off-grid area to lighting social institutes like (health center, school and farmer training centers), households (including to run TV, radio), for telecom towers (network tower) and for town water supply water pumping) (Keriri, 2013). In Ethiopia people are using solar energy in off-grid areas because of the following reasons: populations, low investment cost, reliable power, create local jobs and incomes for disturbers (Keriri, 2013).

The majority of the population (i.e., around 80%) live in the rural area without access to grid electricity, and this makes the country a good case for studying both the challenges of clean energy access and the adoption of household solar energy technology. The proportion of the rural population that has access to electricity was only 10% compared to an average of 17% for Sub-Saharan Africa in 2013 (Panos *et al.*, 2016). These problems have led to the country needing energy that is reliable, clean and affordable in order to cater for the large numbers of poor rural households. Being located in the tropics, the country has abundant and untapped potential of clean energy resources, such as solar, bio energy, wind, hydropower and geothermal. Ethiopia has already started pursuing a wider diffusion and dissemination of renewable energy in recognition of these prospects (Bais *et al.*, 2018). Solar energy is one of the renewable sources of energy that is abundant, accessible, affordable, inexhaustible, highly available, ecologically and environmentally friendly, in rural Ethiopia the majority of households are still using pollutant kerosene for lightning (Shahsavaria *et al.*, n.d.). Generally, energy sources are traditional and modern. The modern energy sources are kerosene, Liquid Petroleum Gas (LPG) and electricity, and traditional energy sources are firewood, charcoal, crop residues and animal waste (Ashenafi *et al.*, 2023; Bais

et al., 2018). According to Flavin & Aeck, (2005), using renewable energy has a number of advantages, including freeing women's time from survival duties, giving opportunities for money generation, reducing indoor air pollution, increasing health, and providing lighting and cooking for households. Many countries have managed to reduce their dependence on traditional energy systems through new innovations and improved infrastructure while others still depend largely, in some cases almost entirely, on fossil fuels. Ethiopia, for instance, is a country where its energy system is highly dependent on petroleum imports. Different universities and research centers have devoted themselves to find the core of the problem and propose solutions; many industries claim to have reduced their CO₂ emission levels while others keep playing their behind the curtain tricks to maximize profit different societies have showed their commitment to the environment while others, for one or other reasons, fail to live up to that standard (Dawit, 2010). The result of the study will have development and policy significance by providing current and valuable evidence, which can be used by policymakers to make an informed decision in the formulation of effective development programs and strategies related to addressing the rural energy crisis. Hence, solar energy is a good option and recent technology that contributes for proper management of environmental and social resources to minimize environmental impact, deforestation and health effect if properly handled to supply for individual houses or small community in Ziquala district.

1.2. Statement of the Problem

In rural areas of Wag himra nationality administration the whole rural households who are depended on solid fuels such as wood, dung, agricultural residues and local charcoal, to meet up their most basic energy needs like cooking, boiling water, heating, scorch of farm tools and sticks. Ziquala district is continually experiencing rapid rural expansion and population growth, requiring an increase in power generation capacity (ZWWEO, 2023). Wood is also used as the main source of energy in rural households for cooking and other purposes. The energy sector of the country is rather based on oil import and about 96% of the population being dependent on biomass, such as burning of wood, animal manure and crop waste. However, the huge amount of wood consumption, especially in rural areas, is a catastrophe to the environment as tree plantation to replace them is not so common. The resulted deforestation that has been going on for many decades is also a cause to biodiversity loss and soil erosion which in turn affects the balance of the ecosystem. Together with that, the use of wood in rural areas has also social concerns such as

smoke caused health problems, burnings, etc (Dawit, 2010). Therefore, diversification of energy resources by investing in solar energy into the expansion areas is a wise decision, to address energy stress and help to provide a consistent energy supply, optimal economic development, and a better standard of living (Gärtner, & Stamps, 2014). Moreover, integrating carbon-free alternative energy sources to support economic growth in a sustainable manner. To determine this potential, it is crucial to explore what factors support and hinder the use of local energy sources (solar) in these areas. Therefore, this research will explore the currently used indicators in assessing the barriers in solar energy technology to better understand what could possibly hinder solar energy technology in Ziquala district. Therefore, this research is aimed at filling such gaps and evaluates the factors influencing the adoption of solar energy technology in Ziquala district by incorporating the relevant variables (Asmare, & Dawit, 2021). The study was provide potential insights to those who would work on improving the solar energy technologies. However, there is a research gap in these empirical studies in addressing institutional factors such as awareness creation training given to the households either formally or informally. A rigorous understanding adoption of SET by households may serve as an input to the formulation and implementation of informed policy this can consequently speed up the pace of household energy transition towards clean energy (Barzani, 2021).

1.3. Objective of the Study

1.3.1. General objective

The general objective of this study to assess solar energy potential and rigorously analyze the socio-economic, institutional, and cultural factors influencing the adoption of solar energy technologies in Ziquala District, Amhara Region, Ethiopia.

1.3.2. Specific objective

- To estimate monthly average daily solar radiation based on sunshine hour data from three meteorological stations with the required records and then to derive the diffuse and direct components
- Assess solar energy potential in Ziquala district
- To assess the current status and patterns of solar energy technology adoption among rural households

- To identify the key socio-economic, institutional, cultural, and policy-related barriers and drivers affecting the adoption of solar energy technologies in Ziquala district

1.4. Research Questions

1. What is the formula for estimating average daily solar radiation?
2. What are the methods for estimating solar energy potential in Ziquala district?
3. What are the current status and patterns of solar energy technology adoption among rural households.
4. What are the factors that affect adoption of solar energy technology in the study area?

1.5. Significance of the Study

This study is significant because it provide information on how solar energy technologies are used in the district to light homes, produce hot water, heat homes, and generate electricity. And it can also demonstrate the country's solar energy potential. The study would also serve as the basis for future empirical studies and would be used as reference for concerned bodies and institutions. The study focuses on developing a framework for assessing the likelihood of solar energy adoption in Ziquala district. This study identified the potential barriers of solar energy technology in the particular context and developed a framework for assessing it. Hence, it will provide understanding and academic knowledge of solar energy technology potential hindrances/supports. Therefore, other researchers can use the framework to find data and look at the most important barrier for potential solar development. Besides, the results from this study will also provide insight and relevant information for the Ethiopian energy sector, decision-makers, and policymakers to better understand on what to incorporate for the successful development of solar energy in the city. Thus, such a study will help provide the government information on what gaps may exist in solar energy technology contextually.

1.6. Limitation of the Study

During primary data collection, the households were unwilling to response the necessary information. Some respondents were developed reservation to express their opinion as they could not accordingly understand the long term outcome of the study. Not only HH respondents' even local known community figures and leaders were unwilling to integrate to discuss on focus group discussion (FGD). The secondary data present was also fragmented and it was very difficult to access and get the necessary evidence.

CHAPTER 2. LITERATURE REVIEW

2.1. Concept of Solar Energy

Solar energy is a plentiful and environmentally benign source of renewable energy, which is available everywhere on the planet however with significant variance. The primary source of energy for natural processes occurring on Earth's surface is solar radiation (Šúri *et al.*, 2007). A radiation from the sun that is capable of producing heat causing chemical reaction or generating electricity. This is the most abundant energy source on the planet and solar energy is the ultimate source of all energy sources. Solar energy is free the highest cost is collection, conversion and storage has limited the exploitation. Solar radiation can be converted into sustainable produced electricity by using photovoltaic (PV) technology. The physically available solar radiation on Earth's surface is known as solar energy potential (Tanko, 2023). Basically, solar energy is a free resource that is present in different amounts all across the planet. Photovoltaic technology presents a chance for nations and communities to enhance their energy infrastructure and accelerate the shift to low-carbon energy in the current period of global climate change (Betak *et al.*, 2020). Energy that comes from resources that are continuously replenished in nature and typically causes less environmental pollution is referred to as renewable energy.

Examples include geothermal heat, biomass, solar radiation, wind, water, hydropower, and tides. Because they are plentiful and environmentally benign energy sources, they support long-term economic growth (Datta & Karakoti, 2010). Solar PV systems are among the most decentralized forms of renewable technology because of their modular design, which makes them accessible to small and medium-sized enterprises, co-operatives, and individuals who want to manage their own electricity costs and have their own generation facilities (Irena, 2018). A solar PV system consists of the solar module, other electrical and hardware components (i.e. the inverter, battery system, electrical cabling, module mounts, controls, etc.). The solar PV systems can be installed on rooftops or in fields. Solar PV is an environmentally friendly renewable energy source that can be used in households education, health and agriculture, social, communal, commercial and industrial sectors of the economy. Solar PV can be used for lighting, water pumping, cooking, phone charging, vaccine preservation, dairy refrigeration, egg incubation, crop and manure drying, and fish and poultry production, among other things. The advantages of adopting solar photovoltaic (PV) were, among other things, the creation of jobs, increase agricultural yields, and access to a large, clean energy source (Awogbemi *et al.*, 2015).

2.1.1. Solar radiation estimation

The amount of solar radiation received by a specific area is a necessary parameter when planning a solar system. It can be measured directly using pyranometers or photovoltaic sensors, or indirectly by analyzing satellite images or applying calculations on meteorological data (mainly sunshine hour records). In situations where direct measuring equipment is not available (like Ethiopia), indirect methods of radiation estimation are applicable. International organizations such as NASA have previously estimated the solar radiation of Ethiopia on a country level using various techniques. NASA used data gathered for 20 years beginning in July 1983 using satellite observations for 12 Ethiopian towns (Solomon, 2011). Using raw sunshine hour data gathered from 142 Ethiopian stations run by the Food and Agriculture Organization (FAO) and Ethiopian Meteorological Service (EMS), investigated the nation's solar energy potential. Three different techniques have been employed: The modified Angstrom relation based on extraterrestrial radiation, The Angstrom linear relation and Schuepp relation both based on clear sky radiation. Different researches have been done on the solar energy estimation for different countries and they utilized different methods and equations. The first model that used sunshine duration to estimate monthly average daily solar radiation on a horizontal surface is the Angstrom equation (Angstrom, 1924).

$\frac{H_{cal}}{H_o} = a + b \frac{S}{S_o}$, Where: H_{cal} (kWh/m²/day) is monthly average daily global solar radiation on a horizontal surface, H_o (KWh/m²/day) is the extra-terrestrial daily radiation available outside the atmosphere on a horizontal plane. S (hour) = monthly average daily number of hours of bright sunshine S_o (hour) = monthly average daily number of hours of possible sunshine (day light between sunrise and sunset). After this earliest model different researchers have derived different models and equations to calculate the extra-terrestrial daily radiation and the regression coefficients (a and b). According to Solomon, (2011) used a simulation model to calculate the mean daily diffuse solar radiation at four locations in Thailand, SE Asia and compared with rough estimates from correlations between global solar radiation and duration of sunshine. The correlation between daily total global solar radiation and daily duration of sunshine is the same as the one which is derived from Angstrom model. The simulation model results and the results form correlation calculations are then found to be remarkably close.

2.2. Solar Power as a Source of Sustainable Energy

The development of renewable energy sources is necessary for the sustainable development of any country due to depleting fossil fuel level, climbing fossil fuel prices across the world and more recently pressure for reduction emission level. Out of all the technologies based on renewable energy sources, photovoltaic technology is thought to be the most appropriate, especially for distributed power generation (Jamil *et al.*, 2016). Electricity from the PV system is especially valuable when it falls during periods of high demand, such as the summer afternoon peak when air conditioners are being used. In addition to this, solar photovoltaic systems can also increase the reliability of the system to which they are connected, can also reduce transmission and distribution losses as they generate the electricity close to the point where it is consumed. Since climate change threatens to upend the weakest economies and penalize the poorest people, reducing greenhouse gas emissions is especially important for the developing countries. Sea level rise associated with projected increases in temperature could displace tens of millions of people living in low-lying areas. With climate change, the weakest economies will also be faced with new stresses such as resisting the spread of vector-borne diseases.

According to the International Energy Agency (IEA), in 2008 there were an estimated 1.5 billion people, or 22% of the world 's population living without access to electricity, 85% of whom live in rural areas. The IEA predicts that if current policies do not change, by 2030 there will still be 1.2 billion people without access to electricity. The number of people without electricity will even rise in Sub-Saharan Africa. The 2.4 billion people who rely on traditional biomass fuels for their energy must collect and burn straw, dung, and scraps of wood to cook their meals. Access to modern energy reduces hunger and improves access to safe drinking water through food preservation and pumping system (Ushizimpumu, 2016). It fosters education by providing light and communication tools, it improves gender equality by relieving women of fuel and water collecting tasks and it reduces child and maternal mortality as well as the incidences of disease by enabling refrigeration of medication as well as access to modern equipment.

2.3. Solar Radiation Utilization and Development

With less than 15 PV equipment suppliers in Ethiopia, there aren't many solar enterprises currently in operation. However, 90% of the market is supplied by just five or six enterprises. The other suppliers sell Photovoltaic (PV) systems along with many other products with the solar business accounting for less than 5% of their annual turnover. While the private sector is the sole supplier of photovoltaic systems in the

commercial market, it relies heavily on tenders from the public sector REF, Non-Government Organizations (NGOs) and foreign aid missions (Asmelash & Gorini, 2021). The social benefits of modern energy systems extend from health condition improvements to family safety and from economic improvements to a better quality of life. While the majority of the socially diverse but economically poor East African nation's population has no access to modern energy, many experiences the negative consequences of using firewood and different fossil fuels. One of the main socially devastating impacts of using wood as a source of energy in rural households is in connection with the burning of children, housewives and properties in many cases the house itself. Solar photovoltaic has been one of the pioneering renewable technologies over the decades. The total installed capacity of solar Photovoltaic (PV) reached 480 GW globally (excluding CSP) by the end of 2018, representing the second largest renewable electricity source after wind. Last year, solar photovoltaic again dominated total renewable and power capacity additions, adding twice as much capacity as wind and more than all fossil fuels and nuclear together, with solar Photovoltaic (PV) additions reaching around 94 GW (Girum *et al.*, 2021; Irena, 2019).

Ethiopia is one of the energy deficient countries in the world with a net energy importer. The country is potentially endowed with various potential sources of renewable energy. It has the not fully exploited potential of renewable energy up to 45,000 MW from hydropower, 10,000 MW from wind, 5000 MW from geothermal and an average of 5.26 kWh per square meter per day from solar energy. The majority of the energy sources that have been described are either untapped or not fully developed, with the exception of biomass fuel. For example, in terms of hydropower potential, Ethiopia is ranked second in Africa next to the Democratic Republic of Congo (DRC) but has exploited only <10% of its full potential. Ethiopia is one of the Sub-Saharan nations with the greatest potential for renewable resources, despite limited electricity access to its citizen (Développement *et al.*, 2000). Energy use is closely linked to a range of social issues, including reducing poverty, population expansion, urbanization and a lack of opportunities for women.

2.3.1. Benefits of solar energy utilization development

Sustainable development is the important gift that we can leave for our future generations. The development of various renewable energy sources, such as solar, wind, hydro power, biomass, geothermal, and hydrogen gas is crucial for providing the energy required for a nation's sustainable growth. Solar energy is one of the most promising renewable energy sources that could help developing nations like Ethiopia satisfy their energy needs in the future. Solar energy can be used to accomplish this in two ways:

directly by producing heat through the solar thermal effect or indirectly by producing electricity through solar photovoltaic, or PV, panels. At the same time, PV power generation as a solution to the increasing demand for electricity can also minimize environmental and social problems related to fossil fuels and nuclear fuels (Ashenafi *et al.*, 2023). PV systems have grown quickly in recent years, with an average annual growth rate approaching 50% and are starting to progressively replace coal-fired power generation due to their energy and environmental advantages. Ethiopia has substantial solar energy resource. Solar energy is a renewable, sustainable and environmentally friendly clean energy source that is available every day of the year, even cloudy days produce some power, reduces electricity bills and can enhance the value of the homes, can be installed anywhere; from a remote field location to a city building, use batteries to store extra power for use at night, provides energy reliability, energy independence and energy security (Dereje, 2014).

2.4. Solar Energy Potential in Africa and Ethiopia

Africa is rich in solar energy potential, with which most parts of the continent getting annually average irradiance levels of more than 2000 kWh/m² (Szabo *et al.*, 2011). Africa's estimated theoretical potential of solar PV could provide the continent with more than 660, 000 TWh of electricity a year, far above its projected needs. However, its 5 GW of installed solar photovoltaic (PV) capacity accounts for less than 1% of the world's total capacity. Solar energy has the potential to become one of Africa's main energy sources if it is installed properly and with the appropriate policies (Newell *et al.*, 2019). From the part of Africa, east Africa was identified as having the highest theoretical potential more than 200,000 TWh/year. Ethiopia one of the countries in east of Africa has abundant solar energy resources. The national annual average irradiance of the country is estimated to be about 5.2 kWh/m²/day (Ashebir & Desta, 2021). The solar resource is relatively lower in the most populous northern, central and western highlands of the country while the rift valley regions and western and eastern lowlands of the country receive higher annual average irradiance (above 6 kWh/m²/day) (Melessaw *et al.*, 2009).

Despite the country abundance of solar energy resources, only about 14 MW of solar PV have been put to use for large city water heating, telecom service, lighting, and water pumping in rural areas (Dereje, 2014). Ethiopia has currently started the first tender process to construct, own, and operate 100 MW solar PV projects. For one of the projects, which is near Metehara, ENEL Green Power (EGP) was chosen as the preferred bidder; the other two sites which are near Mekele and Humera, were not awarded (Ashebir & Desta K, 2021). In addition to this, country has intended to construct 125 MW solar power plants, which

are the Scaling Solar Gad Phase I in the Somali region and the Scaling Solar Dicheto Phase I in the Afar region (Kiflom *et al.*, 2019). However, until the recent times country's use of PV for meeting off-grid power needs was confined to projects funded by donors that use PV based technologies (distance education radios and vaccine fridges) in remote rural areas (Dorothal, 2019). In the past five years, Ethiopia's solar photovoltaic capacity has nearly tripled. However, 14 MW of solar PV systems has been installed up to now counting for 0.3% of the Nation's total energy capacity. Ethiopia's solar capacity is expected to increase in the coming years with the number of ongoing solar PV projects. In May 2016, the state own power company Ethiopian Electric Power (EEP) initiated the Metehara project, which was Ethiopia's first solar plant tender for 100 MW. The Ethiopian solar market is still at an early development stage with an estimated installed capacity of 5 MWp (Ashenafi *et al.*, 2023). In the 1990s growth was less than 5% but in recent years, it has increased to 15%–20%, mostly due to the telecom sector, which accounts for 70% of installed capacity. 90% of the market is supplied by five or six companies, some of which do not specialize in solar PV.

The market potential is estimated at 52 MW, the majority within the solar home systems (SHS) market and continued expansion in telecom sector (Dereje, 2014). Solar house system has the greatest annual growth rate of 20% with few suppliers and driven by the extension of low-cost housing and real estate developments. In the longer term, the growing inverter charger backup market combined with a feed in tariff law under revision could constitute a precursor to grid connected PV. For the foreseeable future, larger and in particular grid connected PV systems will face stiff competition from smaller hydro power systems, including small and micro hydro power.

2.5. Energy Potential and Consumption Status of Ethiopia

According to Legesse, (2011), Ethiopia is one of the African continent with underexploited energy resources, as evidenced by the fact that substantial energy demands are still satisfied by traditional resources. Currently total energy consumption of country was around 40,000 GWh, in which about 92% are consumed by domestic appliances, 4% by transport sector and 3% by industry. Nowadays Ethiopia total installed capacity for electric generation is approximately 4.5 GW mainly generated by hydropower (90%) and followed by wind energy (7.6%) (Vande Graaf, 2014), with approximately 90% of its total energy consumption coming from bio-energy, while the remaining 4.5% comes from the transportation sector which is primarily powered by imported petroleum and the modern energy contributes only about 6% of

the overall energy consumption (Conti *et al.*, 2016). The exploited amount and exploitable energy potential of the country are displayed in (Table 2.1). According to Ethiopia country report in 2019 only about 45% of the country population has access to electricity. From this urban population has 97% access to electricity, while in rural areas electricity access remains extremely low at about 31% (Dawit *et al.*, 2021). However, only few researches were conducted in Ethiopia to solve problem in rural energy access and empower the development of alternative energy technology.

Table 2.1. Potential and exploited source of energy in Ethiopia.

No	Source	Unit	Exploitable Potential	Exploited Amount	Percentage Exploited (%)
1	Hydropower	GW	45	3.18	~17
2	Solar (day)	kWh/m ⁻² d ⁻¹	5.2		<1
3	Wind	GW m/s	1350	0.324	<1
4	Geothermal	GW	7	0.0073	<1
5	Wood	Million Ton	1120	560	50
6	Agricultural waste	Million Ton	15-20	~6	30
7	Biogas	Household	1-3 million	17869	<1

Source: (Ashebir & Desta, 2021)

2.6. Factors Affecting the Adoption of Solar Energy Technology in Globally

Countries that are popular for solar energy technology, such as US, Spain, Germany, and Italy, focus on adoption of SET. This is because it reduces the cost of power generation infrastructure, increases energy reliability and becomes a source of money for residents. Therefore, the factors discussed in most studies are selected and can be organized according to five general categories: economical, policy and institutional, technological, information and human resource, and societal. This study is

going to look at and assess five factors for their appropriateness for use in the case of Ziquala district. Indicators that are appropriate for the case area are selected from the above studies to measure each barrier.

- ✚ **Economy:** Several studies have highlighted economic factors that could hinder the implementation of solar energy technology. The most mentioned indicators include capital incentives, level of government subsidies, initial costs, repair costs, and tax exemption mechanisms. For instance, Zhang, (2012) which was done in Hong Kong, highlighted the high initial cost of solar energy with reference to the expensive materials needed to install solar panels. Also, Ohunakin, (2014), which focused on cities in Nigeria, explained limited government subsidies as barriers because most governmental supports in the form of subsidies are given for conventional energy sources and this has led to slow solar energy technology. Luthra, (2015), a study in India, explained limited access to financing discourages solar energy investors, small and medium scale enterprises (SMEs) towards solar energy technology.
- ✚ **Policy and Institutional:** Since the policy is the critical engine to fasten the development of solar PV (Wang, 2021), and most of the studies reviewed are related to policies. For instance, Irfan, (2019), which was done in Pakistan, highlighted confusing and uncertain policies discourage businesses and the involvement of private investors in solar PV projects. Also, as mentioned by Do, (2020), to start a solar project in Vietnam, an investor should go across 17 administrative steps, which makes a complex and lengthy process. A study which was done in Nigeria by Do, (2020), argue that the incorporated feed-in tariff scheme into solar energy in the country is not attractive and encouraging for investors since it is expensive and doesn't make the investor profitable.
- ✚ **Technological:** Based on the different studies review technological factor is highlighted as a barrier the development of solar energy. For instance, Do, (2020), which was done in Vietnam, pointed out that grid unreliability is in relation to the inadequate or overload transmission infrastructure (grid). Irfan, (2019), which was done in Pakistan, highlighted the country is dependent on foreign technology for key solar energy parts and equipment due to no solar cells production facility at a national level. Also, Luthra, (2015), which focused on cities in India, point out solar energy technologies in India are inefficient/underperforms because developmental efforts of some relevant solar technologies have not yet been initiated.

- ✚ **Information and Human Resource:** Several studies have highlighted solar energy technology in different areas is experiencing information and human resource challenges. The most mentioned indicators include lack of local experts for operation and maintenance, level of government subsidies, initial costs, unreliable and inefficient solar energy data, limited knowledge of modern solar technologies, and limited investors and suppliers. For instance, Irfan, (2019), which was done in Pakistan, highlighted limited skilled manpower with reference to limited local and international cooperation in and limited training centers. This study also argues that the unreliability and inefficiency of solar energy data is a barrier because the government is not encouraging solar energy- related research and development (R&D) by providing funds. Also, Charles, (2018), which focused on Africa, highlighted limited skilled manpower with reference to the inappropriate designed solar energy policies and to the installation and maintenance of solar equipment. The study further explained the reason for this is the lack of interest to invest in solar energy due to lack of funds and loans for investment.
- ✚ **Societal:** Several studies have highlighted societal factors that could hinder the implementation of solar energy development. The most mentioned indicators include lack of awareness and information for solar energy, limited public participation, and low public acceptance. Do, (2020), which was done in Vietnam, highlighted low public acceptance slow down the implementation of solar energy projects. A study by Nikas, (2020), argue that issues such as public acceptance may be considered as a significant barrier to the energy transition. Therefore, this research will also determine how best to measure the stated societal aspects that hinder the development of solar energy in the context of Ziquala district. These are 1) lack of awareness and information for solar energy, 2) limited public participation, 3) low public acceptance. Moreover, in the literature review, the previous research, which was done about the hindrance aspects to solar energy technology, has a different aspect that varies in different countries, which is dependent on the context of Ziquala district.

2.7. Factors Affecting the Adoption of Solar Energy Technology in Ethiopia

Solar energy in Ethiopia is underdeveloped due to different constraints in both the demand and supply sides (Kebede, 2014). This study further described only less than 1% of the country's solar potential is exploited in off-grid areas. Besides, the 2011 draft energy policy recommended

involving private investors and attract them through the provision of loans, grants, and various incentive mechanisms include the formulation of FiT laws (Kebede, 2015). Reports reviewed from the Ministry of Water and Energy, (2012), and feasibility studies highlighted reducing the bottlenecks in the development of solar energy helps to meet the demand in an efficient and reliable way. The factors found from the above-identified reports and studies are general barriers for solar energy at a national level and are categorized into five general categories as economic, technological, policy and institutional, information & human resource. For a general understanding, a number of categories and an overview of the available indicators are identified under each factor as follows. The indicators for measuring the potential for solar energy development in Ethiopia found from the reports, and feasibility studies are:

✚ **Economy:** Ministry of Water and Energy, (2012), argued that limited access to financial support and incentive schemes leads to a decrease market size and the number of investors and private suppliers in solar energy. Another study by UNIDO., (2010) also explained the currency issue as a constraint for suppliers, investors, and the whole energy sector. Banks and institutions are the main actors needed to provide loans for the suppliers, investors, individual users, promoters, and designers; however, access to financial support for solar energy projects, including solar, is limited and at an early stage (Kassa, 2019). In general, the main factors measuring economic aspects limiting the development of solar energy in Ziquala district are capital intensive, low financial support, low income, high foreign currency needed, limited tax exemption and bank loans, lack of access to financing for research and development, promotion and dissemination, lack of a market link between various solar energy actors, lack of access to credit facility for enabling communities to use solar energy and lack of fund for solar technologies.

✚ **Policy and institutional:** it is believed that having unimplemented FiT mechanisms discourage investors from entering the solar energy business (Ministry of Water and Energy, 2012). Other barriers include not clear policy, limited institutional support, and participation, weak institutional arrangements and capacity building, poor sector management, and inadequate infrastructure, lack of stable institutions, limited private sector participation, lack of effective monitoring and evaluation strategies to develop solar PV technology. Furthermore, the quality of the imported materials is another issue hindering solar development because the controlling quality of such products in

a free market-based economy is difficult (Kassa, 2019). The study also claimed that Ethiopia lacks a “national quality regulation” agency, which leads to people importing lower-quality solar components due to the low cost.

✚ **Technological:** According to the UNIDO., (2010) and (Kassa, 2019) studies, solar cells, batteries, and most of the technological materials needed for assembling are imported from China, Germany, and India. Kassa, (2019) further highlighted due to the lack of local industry, the price of solar materials is highly affected by the increased foreign exchange rate, and most of the suppliers do not import certified quality solar technology materials.

✚ **Information and Human Resource:** Ministry of Water and Energy, (2012), report highlighted lack of local skilled human power to carry out maintenance, absence of sufficient information and data, lack of feasibility studies. Also, detailed data at a specific site, town, or city level is stated in the report as a barrier. A feasibility study by UNIDO., (2010) argued that due to the hard currency problem in the country, it is difficult for suppliers to import solar technologies. This study also mentioned the national and international companies involved in the energy sector also suffered because of the foreign currency shortage to import raw materials needed for assembly.

✚ **societal:** the Ethiopian energy sector report, Ministry of Water and Energy, (2012), mentioned societal barriers affecting solar energy in general at a national level. These include a lack of appropriate media for solar energy advertisement, lack of motivational awareness, dependence on traditional sources of energy, low private sector participation, and lack of local community participation, ownership in RE projects were assessed. Integration of solar energy players for promotional activities, sharing of experiences and resources would be mandatory and a better method to reap mutual benefits in a country with limited resources and such an unspoilt market throughout the country (Kebede, 2014).

CHAPTER 3. MATERIAL AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Ziquala district is one of the districts in the Wag Himra Zone, Amhara National Regional State (ANRS) in Ethiopia. It is located 65 km from zone town of Sekota, 503 km from Bahir Dar, and 784 km from Addis Ababa, Ethiopia. The major town in Ziquala district is Tsitsqa. It is bordered on the south by Dehana district, on the west by the Tekeze River, which separates it from the North Gondar and Sehalala districts, on the north by Abergele district, and on the east by Sekota district (Figure 3.1). The district town, Tsitsqa is located at 12° 30' 0" N - 13° 10' 0" N latitude and 38° 30' 0" E - 38° 50' 0" E longitude and an altitude of 1462m above sea level. Ziquala district has 15 kebeles according to the Ziquala woreda agricultural development office survey, 2024

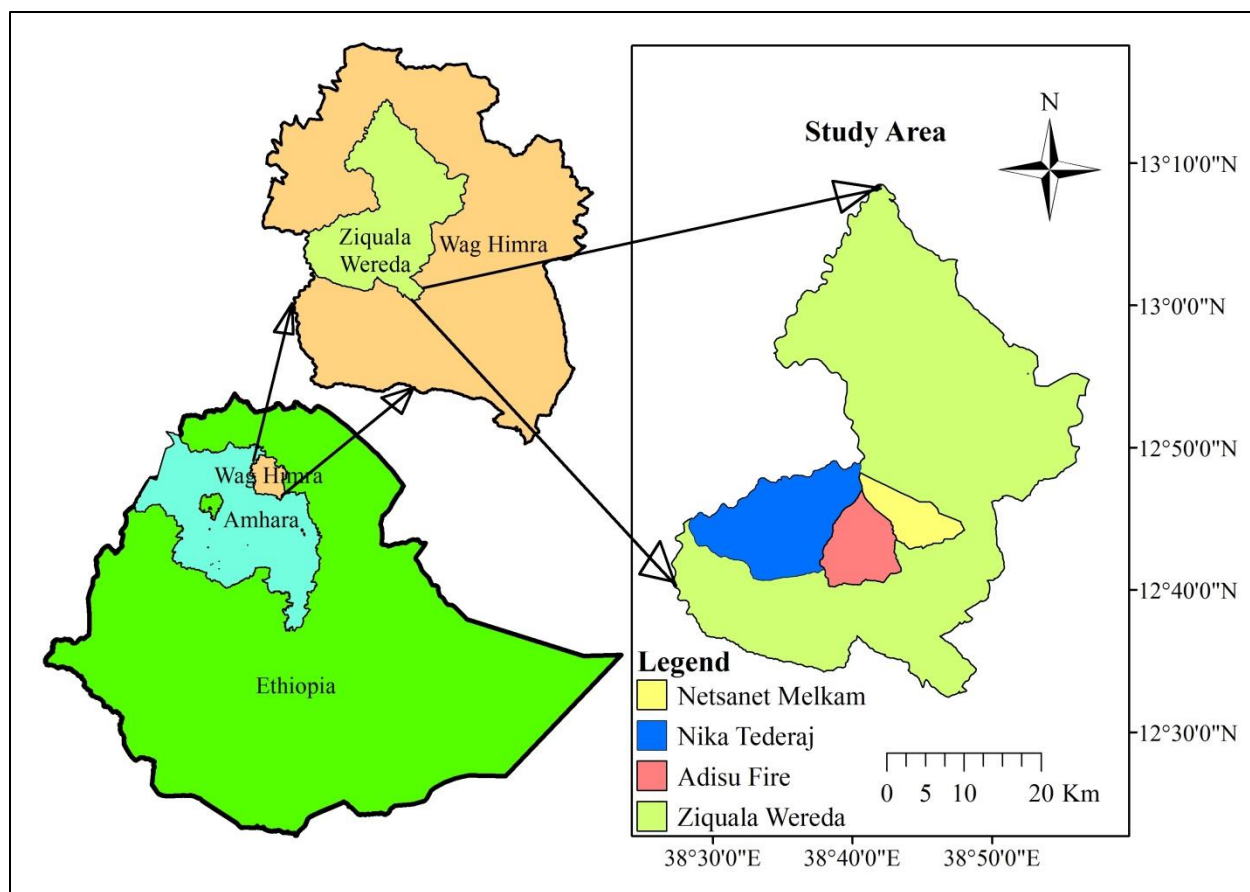


Figure 3.1. Location map of the study area

3.1.2. Climate

In Ziquala district the rainfall patterns is unimodal, short and erratic that extends not more than two months per year, usually from end of June to the end of August. At 500-1500m a.m.s.l the district agro ecological areas are kola. The annual average rainfall and temperature in Ziquala district was 255mm and $>28^{\circ}\text{C}$ respectively (Dereje, 2004).

3.1.3. Topography

The erratic seasonal rainfall coupled with the steep slopes topography with low vegetation cover have led to low retention of ground water and high run-off, which in turn led to extensive soil erosion in the district. Erratic rainfall, rugged topography, population pressure and traditional agricultural practices in the area have led to severe natural resource degradation. Crop production usually fails due to low soil fertility and

high moisture stress, almost every year. The majority population is dependent on food aided organizations (NGOs and Governmental organizations).

3.2. Data Sources

Various studies have been conducted in different countries regarding factors affecting adoption of solar energy technology. The identified factors in those studies provided very useful information for further studying these barriers in the context of Ziquala district. Therefore, a semi-structured interview, questionnaire from the relevant stakeholders, and relevant document reviews were conducted to understand the extent to which the barriers found in the literature are applicable in Ziquala district. The source of the meteorological data for estimation of solar radiation is the National meteorological agency in Eastern Amhara Kombolcha Center. Sunshine hour records of three meteorological stations which make such kind of measurements were collected. The primary data were collected from selected households of study area. Hence, data on demographic and socioeconomic variables, institutional variables, awareness about solar energy, the availability of solar energy technology, adoption of solar energy technologies and other relevant information were collected from sampled households. Different techniques were used to acquire primary data. Through a survey of houses utilizing a questionnaire, primary data was mostly connected to respondents' demographic features, people's attitudes towards solar energy technology.

To understand the phenomenon of interest, methods of data collection were chosen: a semi- structured questionnaire, interviews with key KIs, focus group discussion, and documentary research. The data collected from documentary research includes literature review from research reports, official data, such as legal and energy policy documents, feasibility studies, green economy strategy document published by officers in energy sector office, official reports from governmental and creditable organizations is used. Moreover, data from secondary sources that are relevant to the problem were gathered from publications of government offices such as regional/zone/districts IEA, CSA, regional and federal MOWIE involved in development and access to energy activities in the study area.

3.3. Sampling Technique and Sampling Size Determination

According to this study, drawing a sample is crucial in academic studies since the population is too large, costly to administer, time and resource-consuming for us to consider collecting information from the whole population. The sample size is decided considering time, resources, and data management challenges. Purposive sampling is used to select the

case study site. The main reason is selecting the best representative of rapidly expanding rural areas with large areas and population numbers (Guest, 2019). Initially, the Wag himra zone was specifically selected due to its potential as a site for advancing domestic solar energy technologies in the Amhara National Regional State. Second, the zone has been divided into eight districts, including one administrative town namely Sekota, Ziquala, Abergele, Sehala, Gazgibla, Dehana, Tsagbji, and Sekota town administration. Then Ziquala district was chosen for a variety of reasons. Compared to other Wag himra zone districts, this one has low level of awareness in solar energy adoption. The target populations for this study were household from the districts in the three kebeles were chosen because of the distribution of the adoption of solar energy technology among those kebeles were the same (ZWWE0, 2023).

First, out of 15 kebele in the district, only three kebele was purposively selected such as Nika Tederaji, Adisu Frie and Netsanet Melkam kebele because they have easy access to transportation and a lot of deforestation, which has an influence on health and environment, thus using SET to resistance this challenge and to manage the natural resource (ZWWE0, 2023). Each sample respondent was chosen at random from the list of sample rural households in each sample kebeles. Then, both household heads that were found in the three kebeles were intentionally taking sample for solar energy technology adopters. Second, using the formula suggested by (Yamane, 1967), the number of sample household head was the target population of the three kebele (Nika Tederaji, Adisu Frie and Netsanet Melkam kebele) was estimated at 95% confidence level and the precision level (sampling error) e is 0.05 (5%). The formula suggests that this error level defines the margin with in which we expect the true value to fall.

The formula to calculate sample size is shown as:

$$n = \frac{N}{1+N(e^2)} \dots \dots \dots \text{eqn (3.1)}$$

Where n is the sample size, N is the population size (total number of household head in the three kebeles), and e is the level of precision (sampling error) at the 95% significance level. The number of household

head for Nika Tederaji, Adisu Frie and Netsanet Melkam kebele is 1050, 639, and 1040, respectively, which is a total of 2729 household heads in three kebeles.

Therefore, the sample size is: $n = \left(\frac{2729}{1+2729(0.05^2)} \right) = 349$

Then, the probability proportional to the size of the sampling procedure was used to calculate the number of household samples from each of the three kebeles was chosen (Table 3.1). Finally, a basic random sampling method was used to pick the three kebeles from survey households. Accordingly, the calculated sample size was approximately 349 household heads that are random sampling from the three kebeles.

Table 3.1. Distribution of sample sizes in each selected kebeles

Kebeles	Total number of HH	Sample size taken
Nika Tederaji	1050	134
Adisu Frie	639	82
Netsanet Melkam	1040	133
Total	2729	349

3.4. Method of Data Collection

3.4.1. Household survey data collection

The fundamental research question of interest was exploring the factors affecting solar energy technology in expansion areas Ziquala district. This study employed both qualitative and quantitative methods of research approach for data collection and analysis through content analysis and descriptive statistics. Questionnaires, interviews and focus group discussions were used to collect data. This study adopted semi-structured interviews for professionals and academics in energy-related sectors to understand factors affecting solar energy technology. In this study, the selection of relevant and reliable indicators to measure the factors was through a review of literature from other countries and adjusted to the local context of the case area. A structured questionnaire was used to gather data from the household survey. It was designed in such a way that it provides information was acquired by a questionnaire survey on the personal characteristics of household head's such as age,

gender, educational level and socio-economic perspectives like household income, and other economic variables, land size energy sources used by households, and other relevant variables to the problem. Structured questionnaires that were contained closed ended types of questions were prepared and gathered from the sample respondents.

Closed-ended questions were used to gather data about respondents' attitudes toward the function of SET. To obtain uniform data the questions that were asked of every respondent are the same. The data collections were administered by enumerators who know the language and culture of the study area. The use of questionnaires enables the respondents to remain anonymous and be honest in their responses. Moreover, focused group discussions (FGDs) were conducted from the selected model households and other concerned stakeholders to supplement the survey data. The detailed socio-economic data of the target households were gathered using direct observation. The participants who were involved in the pretest were those who have adopted solar energy and who haven't adopted solar energy technology. The enumerators checked by asking the samples whether they had participated in the pre-test and by confirming this with the records. Hence, the data collections were carried out under the close supervision of the researcher. The field work for this study would take place during April 1th to 30th in 2024 with trained enumerators.

To know the level, availability and adoption of solar energy technology in the study area, observation was used. The observation was made mainly focusing on site conditions. To undertake the observation activities more efficient, observation checklist was prepared and the information with regard to the observations made were documented and recorded and taken photos. Additionally, a camera would be used to capture some structures and events that are crucial to this investigation. Structured questionnaire interviews would be administered to households in order to gather information on key variables used in this study. After households responded, structured interview was used to get information from zonal experts, local NGOs of contracts, kebele experts and district agricultural experts. Because it allowed the researcher to ask a series of questions face to face and gathered in-depth information freely to explain the problem.

Focus group discussions (FGD): FGDs were held with 12 purposively selected persons from different backgrounds in three groups by dividing three in each group from the sample kebeles. In this study, focus group discussions were held in the study communities before the household survey. The participants involved were representatives of various kebele of the rural communities in terms of age and gender. The participants were asked to express their own feelings (perceptions) and to offer their experiences regarding the issue under study. The people who included in the discussion were local elders, kebele leaders and priests, both poor and rich women and men farmers, youth and adult men, and socially respected farmers who are known to have better knowledge of the present and past, environmental, social and economic status of the study areas. Selected questions from structured and unstructured questionnaire were used to focus group discussions.

Key informants interview (KII); were carried out with a total of 10 purposively selected key informants consisting of jointly with two model household-head and one local district solar expert (field research assistants), one local and district level solar technology promoters, one solar PV importers, one distributor, one retailers and technicians and two selected male and female solar user household head. The purpose was to understand the overall picture of solar technology dissemination, use, market trends, and challenges facing users. In addition, secondary data were gathered from lighting Africa, solar plaza, solar aid and several published and unpublished research works and government and NGO reports.

3.4.2. Methods of radiation estimation

The sun supplies energy in the form of radiation, without which life on earth could not exist. But it is not all of the energy from the sun that reaches the earth's surface. The intensity of solar radiation outside earth's atmosphere depends upon the distance between the sun and the earth. Sunlight on earth's surface comprises a direct portion (comes from the direction of the sun) and a diffuse portion (scattered from the dome of the sky and has no defined direction). The sum of the direct and diffuse radiation is known as global radiation. The global radiation varies greatly depending upon the geographical position of the area and the different seasons during a year. Solar radiation reaching the earth surface is on average of 1000 Wm^{-2} although this depends on the latitude and altitude, the angle of the surface and the direction faced, the degree of pollution and shade, the time of year and the time of day and the thickness of the cloud layer (Solomon, 2011). In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance.

The best way of knowing the amount of global solar radiation is to install pyranometers or photovoltaic sensors at as many locations as possible in the given region and look after their day-to-day maintenance and recording. But it is not affordable for most of the developing countries like Ethiopia. In such cases, indirect estimation can be a useful option. Solar radiation estimation techniques can be broadly grouped in to two categories with one based on satellite observations while the other bases ground level measurements of sunshine hour and other meteorological parameters. There have also been some trials to correlate the solar radiation of one location with other factors like altitude, latitude and longitude in order to have a better estimate of solar radiation (Angstrom, 1924).

3.4.3. Estimation of monthly average daily solar radiation

Solar radiation data are very important for the development and applications of solar energy technology. The most commonly used parameter for estimating global solar radiation is sunshine duration (Solomon, 2011). After revising different methods employed in Ethiopia and other countries, based on its applicability in the study area, a modified Angstrom relation improved by Nadir & Mansell, (2000) is selected for application in the study area. The reasons, that made this scheme a better choice, are: its simplicity as it is based on linear Angstrom relation, it's well checked applicability in nearby locations, its better accuracy in estimation associated with the greater number of factors it considers, its suitability for applications in areas where there is limited radiation data available as it incorporates correlation of radiation with the location's GPS in addition to the sunshine hour ratio and its applicability even for areas without sunshine duration measurements by taking sunshine hour record of the nearby station and inserting the latitude and altitude of the actual location. The major steps in estimating the daily global solar radiation of a station using the Angstrom equations are to collecting sunshine hour record data for 10 years at 3 meteorological stations in below (Table 3.2).

Table 3.2. Collected sunshine hour data

No	Station	Years	Period	Latitude	Longitude	Altitude
1	Tsitsqa	10	2009-2018	13.09	38.29	1462
2	Amdework	10	2009-2018	12.35	38.75	2421
3	Lalibela	10	2009-2018	12.07	39.04	2476

The Angstrom type regression equation was originally developed to estimate monthly solar radiation and it is related with the monthly average daily radiation to the clear day radiation at the location and the average fraction of possible sunshine hours (Angstrom, 1924). The selected method is primarily based upon the very former and widely used Angstrom linear relation which is described as:

$$\frac{H_{cal}}{H_o} = a + b \left(\frac{S}{S_o}\right) \dots \dots \dots \text{eqn(3.2)}$$

where H_{cal} is the monthly average daily global radiation, H_o is the monthly average daily extraterrestrial radiation, S is the monthly average daily hours of bright sunshine, S_o is the monthly average day length, and a and b are regression coefficients. The values of the monthly average daily extraterrestrial radiation on a horizontal surface (H_o) can be calculated from the following equation (3.3) (Duffie & Beckman, 2013):

$$H_o = \left(\frac{24}{\pi}\right) I_{sc} \left[1 + 0.033 \cos\left(\frac{360n}{365}\right)\right] * [\cos \phi \cos \delta \sin W_s + \left(\frac{2\pi W_s}{360}\right) \sin \phi \sin \delta] \dots \dots \text{eqn(3.3)}$$

Where I_{sc} is the solar constant ($=1.367 \text{ kW m}^{-2}$), ϕ is the latitude of the site, δ is the solar declination, W_s is the mean sunrise hour angle for the given month and n the number of days of the year starting the first of January. The solar declination (δ) and the mean sunrise hour angle (W_s) can be calculated by the following equations respectively in (Akinoğlu & Ecevit, 1990):

$$\delta = 23.45 \sin\left[360 \frac{284+n}{365}\right] \dots \dots \dots \text{eqn(3.4)}$$

$$W_s = \cos^{-1}[-\tan(\phi) \tan(\delta)] \dots \dots \dots \text{eqn(3.5)}$$

For a given month, the maximum possible sunshine duration (monthly average day length (S_o) which is related to W_s , the mean sunrise hour angle can be computed by using the following formula (Duffie & Beckman, 2013).

$$S_o = \frac{2}{15} W_s \dots \dots \dots \text{eqn(3.6)}$$

Then applying a regression analysis using Ms-Excel to know the value of the regression coefficient a and b has been calculated from the relationship equation given by (Gana *et al.*, 2014):

$$a = -0.110 + 0.235 \cos \phi + 0.323 \left(\frac{S}{S_o}\right) \dots \dots \dots \text{eqn(3.7)}$$

$$b = 1.449 - 0.553 \cos \phi - 0.694 \left(\frac{S}{S_0}\right) \dots \dots \dots \text{eqn(3.8)}$$

Finally, in this study checking out the accuracy of the estimated monthly average daily global solar radiation data was using the statistically tested by Mean Bias Error (MBE), Root Mean Square Error (RMSE) and Mean Percentage Error (MPE%) to evaluate the error between the estimated and calculated values of solar radiation in spatial distribution. For better data modeling, these statistics should be closer to zero (Tegenu 2019b). These tests are the ones that are applied most commonly in comparing the models of solar radiation estimations in MPE, MBE and RMSE are defined as below.

The Root Mean Square Error: The root mean square error is defined as:

$$\text{RMSE} = \left\{ \frac{[\sum_{i=1}^n (H_{i,cal} - H_{i,estim})]^2}{n} \right\}^{\frac{1}{2}} \dots \dots \dots \text{eqn(3.9)}$$

The value of RMSE is always positive, representing zero in the ideal case. The normalized root mean square error gives information on the short-term performance of the correlations by allowing a term-by-term comparison of the actual deviation between the calculated and estimated values. The smaller the value, the better is the model's performance.

The Mean Bias Error: This test provides information on long-term performance. A low MBE value is desired. A negative value gives the average amount of underestimation in the calculated value. So, one drawback of these two mentioned tests is that overestimation of an individual observation will cancel underestimation in a separate observation.

$$\text{MBE} = \frac{\sum_{i=1}^n [(H_{i,cal} - H_{i,est})]}{n} \dots \dots \dots \text{eqn(3.10)}$$

The Mean Percentage Error: The Mean percentage error is defined as

$$\text{MPE} = \frac{\sum_{i=1}^n [(H_{i,cal} - H_{i,est}) \times 100]}{H_{i,cal} \times n} \dots \dots \dots \text{eqn(3.11)}$$

Where; $H_{i,cal}$ and $H_{i,est}$ indicates calculated and estimated values of daily solar radiation in $\text{kwhm}^{-2}\text{d}^{-1}$ respectively. n = number of observations in year. A percentage error between -10% and $+10\%$ is considered as acceptable value (Natei *et al.*, 2022).

3.4.4. Driving direct and diffuse components from global radiation

Two fundamental methods were also used to detect solar radiation directly and its components, both direct and diffuse. Beam radiation is the solar radiation received from the sun without having been scattered by the atmosphere. Beam radiation is often referred to as direct solar radiation; to avoid confusion between subscripts for direct and diffuse. Diffuse radiation is the solar radiation received from the sun after its direction has been changed by scattering by the atmosphere. Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation the definition used to distinguish the diffuse solar radiation from infrared radiation emitted by the atmosphere. The values are measured either by using ground-based instrumentation as pyranometers or remotely with satellites. Diffuse insolation is produced by complex interactions with the atmosphere which absorbs and scatters, and the earth's surface, which absorbs and reflects. The method used by Abdel-Hadi, (2021) to estimate the diffuse fraction of sunlight from the monthly average clearness index (K_t) is used in this study. Then, the monthly mean of daily global radiation H was normalized by dividing with monthly mean of daily extraterrestrial radiation H_o .

The clearness index (K_t) which provides the percentage of incoming global solar radiation that is deflected by the sky can be defined as the ratio of the calculated/estimated horizontal terrestrial solar radiation (H) to the calculated/ estimated horizontal/extraterrestrial solar radiation (H_o) and therefore indicates both level of availability of solar radiation and changes in atmospheric conditions in a given locality (Falayi *et al.*, 2011).

$$K_t = \frac{H}{H_o} \dots \dots \dots \text{eqn}(3.12)$$

Where H is the global solar radiation and H_o is the extraterrestrial radiation.

If $\omega_s \leq 81.4^\circ$ and $0.3 \leq K_t \leq 0.8$,

The diffused solar radiation, H_d is given as.....

$$\frac{H_d}{H} = 1.391 - 3.560K_t + 4.189K_t^2 - 2.137 K_t^3 \dots \dots \dots \text{eqn (3.13)}$$

If $\omega_s \geq 81.4^\circ$ and $0.3 \leq K_t \leq 0.8$,

$$\frac{H_d}{H} = 1.311 - 3.022K_t + 3.427K_t^2 - 1.821 K_t^3 \dots \dots \dots \text{eqn (3.14)}$$

The procedure to estimate H_d , the monthly average daily diffuse radiation on a horizontal surface from estimated or calculated values of H . H_d can be calculated from the following equation (Rani & Sud, 2015). Beam radiation can be calculated from the following equation.

$$H_b = H - H_d \dots \dots \dots \text{eqn(3.15)}$$

The total solar energy received on an inclined surface is the sum of beam and diffuse radiations directly incident on a surface and reflected radiations (reflected by the surroundings).

3.4.5. Interpolation and mapping solar radiation assessment using Arc GIS

Interpolation and mapping tool in Arc-GIS is a suite consisting of a group of geographic information system (GIS) software products produced by Esri. GIS is a computerized system that processes information about anything that has a place on Earth's surface, i.e. has coordinates and descriptions about those features in a tabular form. The estimated values of horizontal radiation for the three stations are overlaid on Arc - GIS shape file of Wag himra zone and neighboring station. Then, the values for the other places in the stations are estimated by employing interpolation tool of Arc-GIS. The employed interpolation technique is Inverse Distance Weighted method. Inverse distance weighting (IDW) is a method for multivariate interpolation, a process of assigning values to unknown points by using values from usually scattered set of known points. The value at the unknown point is a weighted sum of the values of N known points. A general form of finding an interpolated value u at a given point x based on samples $u_i = u(x_i)$ for $i = 0, 1, \dots, N$ using IDW is an interpolating function:

$$u(x) = \begin{cases} \frac{\sum_{i=1}^N w_i(x) u_i}{\sum_{i=1}^N w_i(x)}, & \text{if } d(x, x_i) \neq 0 \text{ for all } i, \\ & \text{if } d(x, x_i) = 0 \text{ for some } i, \end{cases}$$

Where,

$$w_i(x) = \frac{1}{d(x, x_i)^p}$$

It is a simple IDW weighting function, as defined by (Kalota & Khan, 2022), x denotes an interpolated (arbitrary) point, x_i is an interpolating (known) point, d is a given distance from the known point x_i to the unknown point x , N is the total number of known points used in interpolation and p is a positive real number, called the power parameter. Here weight decrease as distance increase from the interpolated

points. Greater values of p assign greater influence to values closest to the interpolated point. The thematic map is, then, drawn to show the radiation distribution in the study area by dividing the radiation values into the sections. Finally, contour lines are drawn on the map with the contour intervals to show the equipotential areas. Accordingly, the Angstrom equation was used to assess solar energy potential of the study area was employed (Solomon, 2011).

3.5. Method of Data Analysis

The data collected was first subjected to qualitative methods of data analysis where the questionnaire was subjected to scrutiny by checking for completeness. The questionnaires that are deemed to be complete would be the numbered and the response coded and keyed into Statistical Package for Social Science (SPSS) version 27 analysis. To identify links between variables and draw conclusions, a full statistical analysis was performed after thoroughly cleaning the data and verifying for any incorrect entries. It was important to ensure the sampling method had no bias in the way the sampling was implemented. Cleaning, coding and classifying of data enhanced the use of statistical methods for analysis. The data analysis was involved quantitative and qualitative methods.

3.5.1. Qualitative data analysis

Qualitative data was analyzed based on content analysis. Data was obtained from key informant interviews, focus group discussions and direct field observations were analyzed based on content analysis. The data was gathered using observation used to counter-check information provided by household respondents and focus group participants.

3.5.2. Quantitative data analysis

Quantitative data was analyzed using descriptive and inferential statistics. Descriptive statistics were used to describe relevant aspects of variables and to provide detailed information about socio-economic and demographic household characteristics. Quantitative data analysis was done through descriptive statistics to analyze the data. Descriptive analysis is the process of converting raw data into meaningful information using frequency, percentage, mean and standard deviation. Descriptive statistics enable a researcher to derive patterns that are not clearly apparent in raw data through the use of visual aids and graphical representations such as pie charts and frequency tables. In this study descriptive statistics were used to analyze the gender of respondents, age groups, marital status, income levels and education levels.

Inferential statistics such as Pearson correlation regression analysis was used to determine the relationship between factors and adoption of solar energy technology.

Pearson correlation is the best method of measuring the association between variables of interest because it is based on the method of covariance. It gives information about the magnitude of the association or correlation as well as the direction of the relationship. Whether the correlation between the two variables are positive or negative. This method enables the research was estimating the value of a dependent variable with reference to a particular value of independent variable through regression equations. This study was employed use regression and correlation tests as a form of inferential statistical analysis in order to determine the relationship between the dependent and independent variables.

3.6. Econometric Analysis of Model Specification

Regression analysis is a statistical process for estimating the relationship between a dependent variable (the outcome or the result to analyze) and one, or several, independent variables (the investigated, possible, explanatory variables). The key benefit of using regression is that it indicates if independent variables have a significant relationship with a dependent variable. The study used binary logistic regression model is the most widely used model in adoption research. Other factors which affect solar energy technology adoption was showed in some literatures are also used in this study. In the present study the dependent variable is a dichotomous take on a value of 1 if a household adopted solar energy technology and non-adopter it has a value of 0 (Asmare & Dawit, 2021). The logistic regression model was applied to examine the factors affecting adoption of solar energy technology. The reason behind using this model in the study than the probit model is that the equations of the logit model are directly interpretable as log-odds (Asmare & Dawit, 2021). This model is also used in previous studies by several researchers for the same issue, for instance, Dawit, (2018) and Anaba & Olubusoye, (2021). According to Park, (2013), there are two models of logistic regression, binary logistic regression, and logistic regression models. Binary logistic regression is used when the dependent variable is dichotomous (only two categories) and the independent variables are either continuous or categorical (Adeyemi & Akinwale, 2019).

The analysis tools that were used to Excel spreadsheets, SPSS version 27 analysis. The logit regression uses maximum likelihood method to estimate parameters in the model after transforming the response variable into logit (Barzani, 2021). The product of the probabilities of solar energy adoption success and non-adoption specifies the maximum likelihood of the models. The coefficients of the logit model, like the

ordinary regression coefficient, define the parameter estimates. According to Asmare & Dawit, (2021), the equation of the model is written as follows after converting the dependent variable into the natural log of the odds (logit):

$$P_i = E(Y) = \frac{1}{X} = \frac{1}{1 + e^{-(\beta_1 + \beta_2 X_i)}} \text{----- eqn (3.16)}$$

Where (p_i) is the probability of adopting solar energy, (x_i) stand for the set of explanatory variables (i.e. income, level of education, gender of the household head, age of the household head, land size, prior information/knowledge or awareness, credit accessibility, training access, mobile access, media access and own cell phone). When equation 3.16 is the logistic regression equation, let consider, $Z_i = \beta_1 + \beta_2 x_i$ are replaced by Z_i in the first equation, then we obtained equation 3.17.

$$p_i = \frac{1}{1 + e^{-Z_i}} = \frac{e^{Z_i}}{1 + e^{Z_i}} \text{-----eqn (3.17)}$$

In equation 17, Z_i exist between $-\infty$ and $+\infty$ and p_i is between 0 and 1. Where p_i shows the probability of households who use the solar energy technology, and X_i is the explanatory variable, (i) is an individual household observation (where p_i equal to one the probability that households use the solar energy technology and $1 - P_i$, is the probability of households that can be categorized under not using. Then, the probability of households who do not use can be explained in equation 3.18 as follows:

$$1 - P_i = \frac{1}{1 + e^{Z_i}} \text{----- eqn (3.18)}$$

Equation 19 can be obtained by dividing the households who use to those who do not use solar home system. Therefore, the equation is;

$$\frac{p_i}{1 - p_i} = \frac{1 + e^{Z_i}}{1 + e^{-Z_i}} = e^{Z_i} \text{----- eqn (3.19)}$$

Using the natural logarithm of both sides of the equation, equation (20) can be obtained

$$\ln\left(\frac{p_i}{1 - p_i}\right) = \ln = \left[e^{B_0} + \sum_{i=1}^M B_i X_i\right] = Z_i \dots \dots \dots \text{eqn (3. 20)}$$

The binary logistic regression model calculation for this study was given as:

$$B_i = \beta_0 + \beta_1 (X_1) + \beta_2 (X_2) + \beta_3 (X_3) + \dots \dots \beta_n (X_n) + U_i \dots \dots \dots \text{eqn (3.21)}$$

Where: B_i = Binary dependent variables denoted as “1” if the household adopt solar technology and “0” otherwise. Where: “ β_i ”= Vector parameters to be estimated, “ $\beta_1, \beta_2 + \beta_3 + \dots + \beta_n$ ”= constant term, “ $X_1, X_2, \dots, X_n$ ”=are explanatory variables, “ U_i ”= error term, and n = is number of explanatory variables.

$$Z_i = B_0 + \sum_{i=1}^n \beta_i X_i + U_i \dots \dots \dots \text{eqn (3.22)}$$

It is often interpreted as a test that show whether the regression model is specified appropriately or not. Hosmer-Lemshow test were also used to test the goodness of fit of the model. Therefore, the above econometric models were used in this study to analyze the factors determining the household’s adoption of solar energy system.

3.7. Definition Variable and Working Hypothesis

3.7.1. Dependent variable

The household adoption decision for solar energy technology which is dependent variable for logit analysis is dichotomous variable representing the status of the household solar adoption. It would be represented in the model by 1 for solar adopter and 0 for non-adopter households.

3.7.2. Independent variable

It is hypothesized that the household solar energy adoption at any time is influenced by the combined effect of a number of factors. The independent variable hypothesized to have association the household solar adoption was selected based on reviewed literature and scientific research done somewhere else. An effort was also made to incorporate factor that are feasible and pertinent in solar adoption of the Wag himra Zone, Ethiopia in general and Ziquala districts in particular. The definition of explanatory variables that were considered in the econometric model for investigating the decision for household heads solar energy adoption (Table 3.3). This study was mainly aimed at examining factors influencing decisions to adopt solar energy technology used at the household level. In this study, socioeconomic, demographic and institutional variables were expected to be the main factors influencing rural households’ decision to adopt SET (Table 3.3).

Annual household income (AHINC): It is continuous explanatory variable which represent of the annual agricultural income received by households measured in Ethiopia birr (ETB). With regard to the

households' income variables, the study used the gross estimated farm revenue as a proxy for household income. It constitutes income from crop production, fruit, vegetable, animal and animal products and income from different services. Household income is one of the socioeconomic factors that could affect the adoption of a solar energy technology. Some studies found a positive effect of income on the decision for household solar energy adoption (De Groote *et al.*, 2016; Kwan, 2012; Smith & Urpelainen, 2014). In the case of rural Ethiopia, a study revealed that modern energies (e.g., kerosene, solar, and electricity) are luxury goods (Dawit, 2012). Many scholars indicated that as households' income gets higher, their propensity to adopt the solar energy technology also increases compared to their counterparts (Christian, 2019; Dawit, 2018; Keriri, 2013; Legesse & Chawla, 2016). Thus, in this study household income was expected to have a positive influence on SET adoption.

Sex of the household head (SEXHH): It is dummy explanatory variable that takes value of 1 if the household head is male and 0 otherwise. The variable playing a key role in influencing households' investment decision on renewable energy technology. Studies have indicated that women participate in environmentally friendly technologies more than men. By contrast, one study showed that males were more likely to adopt new technologies compared to female (Bollinger & Gillingham, 2012). In rural Ethiopia, the male is considered to be strong, resourceful, and autonomous decision maker in deciding the adoption of modern technologies, but women are most affected by the lack of access to clean energy. Therefore, the effect of the household head sex on PV solar energy technology adoption is indeterminate. Regarding sex of household head there are two contrasting groups which means the first group argued that male-headed households are more likely to adopt solar energy technology (for instance (Christian, 2019) and in the other side, female headed households are more likely to adopt solar energy technology (Dawit, 2018; Patrick, 2007). Therefore, in this study sex of the household head was expected to have either a positive or negative influence on solar energy technology adoption.

Landholding size (LANS): It is the continuous explanatory variable indicates total landholding size owned by households and measured in hectares (Ha). The larger the household landholding size, the greater their agricultural output which in turn augment income to uptake solar energy technology (Barzani, 2021). According to Dawit, (2018) studies show that having large landholding size increases the probability of adopting solar energy technology. Moreover, asset variables (land holding size) positively affect solar energy adoption since they are the main source of households' income in rural areas. Therefore, in this

study the household landholding size was expected to have positively influence households' willingness to adopt SET.

Age of household head (AGEHH): It is discrete explanatory variable peculiar to household head and measured in years. It assumed to influence household investment in solar energy technology either positively or negatively. Some literature revealed that older household heads are less likely to adopt solar energy technology compared to younger ones. That means it has a negative influence on the household's willingness to adopt a solar energy technology (Christian, 2019; Legesse & Chawla, 2016). But other studies found that households 'age has a positive influence on solar energy technology adoption because it might be related to the fact that older household heads may be wealthier as they accumulate more productive resources that enable them to invest in the solar energy technology (Dawit, 2018). In this study age of households head was hypothesized to affect solar energy adoption either positive or negative influence on adoption of SET.

Marital status (MARST): It is dummy variable that takes value of 1 if the household heads a single, 2 if married, 3 if divorced and 4 if widowed. A study stated that married household heads are more likely to adopt a solar energy technology than either single or divorced household heads (Christian, 2019). The variable was expected to have a positive influence on the adoption of SET.

Educational level of household head (EDULHH): It is dummy explanatory variable which refers to the education level of the household head in grade completed. This variable level is considered a key driver of solar energy technology adoption, namely the education level of the household head. Household head that are more educated tend to acquire a greater awareness regarding the benefits of SET these benefits include health, environmental, economic, and social welfare. In developed countries, a study found a positive effect of education on household solar panel adoption (Kwan, 2012; Rahut *et al.*, 2018). On the contrary, another study found negative effect of education of solar PV technology adoption rate (De Groote *et al.*, 2016). However, in the case of low-income household differences in educational status is an important determinant of how people acquire and use information on solar PV technology and its benefits. Individuals who are less educated may lack awareness about the benefits of solar PV technology.

Therefore, the model is controlled for the educational level of the household head, and it is proposed that positively influence the household's decision on solar energy technology adoption. Regarding education, studies revealed that the education level of household heads has a positive effect on solar energy

technology adoption (Abera, 2019; Christian, 2019; Dawit, 2018). This is because of the reason that education enhances individuals 'health and environmental awareness that helps them to choose clean and modern energy sources. Thus, in this study, the educational level of household heads was expected to positively influence the adoption of SET.

Prior information (PRIORINF): It is dummy explanatory variable that takes value of 1 if the household have information or knowledge about solar energy and 0 otherwise. Awareness or knowledge that households have about solar energy is considered as one driving factor of solar energy adoption. A study found that there is a positive relationship between the adoption of a solar energy and awareness or knowledge about the technology (Naomi, 2014). Therefore, this study was proposed to positively influence on the adoption of SET.

Access to solar training (ACSET): It is dummy explanatory variable that takes value 1 if household gets access to solar related training formally or informally and 0 otherwise. Training is one of the institutional factors considered as a key driving factor of solar energy technology adoption at the household level. Training given for households about the solar energy technology has a positive effect on their decision to adopt (Keriri, 2013). The other study also added that training can help people to be more confident about the innovations for adoption and active usage of the technologies provided (Mbachu & Bizien, 2017). Therefore, in this study, the training was hypothesized to positively affect SET adoption.

Access to media (ACM): It is dummy explanatory variable that takes value of 1 if the household gets access to different media (TV or radio) and 0 otherwise. Media accesses create exposure to households to be more aware of new and timely information about new technologies (Barzani, 2021). Regarding this, a previous study revealed that accessibility of modern communication technologies including radio found to have a positive influence on the adoption of modern and clean energy technologies (Abera, 2019). Thus, in this study media access was expected to have a positive effect on the adoption of SET.

Owning mobile phone (OWMP): It is dummy explanatory variable that takes value of 1 if household has cell phone and 0 otherwise. Mobile phone access creates exposure to households to be more aware of new and timely information about new technologies through online and offline. Regarding this, a previous study revealed that accessibility of modern communication technologies easily available when the household has mobile cell phones (Barzani, 2021). Thus, in this study owning mobile phone was expected to have a positive effect on the adoption of solar energy technology.

Access to credit (ACCRT): It is dummy explanatory variable that takes value of 1 if household gets access to the credit and 0 otherwise. Likewise, credit accessibility is the other institutional factor to be estimated in the model. One literature stated that an increase in accessibility of credit enhances household adoption of new technologies (Mishra, 2018). This is because it can assist rural households to purchase technological products they needed (Barzani, 2021). Therefore, access to credit was expected to have a positively effect on the adoption of solar energy technology.

Table 3.3. Description of Variable explaining and their expected effect on the adoption of SET

Variable	Description	Expected sign	Source
Income	Continuous variable, birr	+	(Christian,2019;Dawit,2018 ;Legesse&Chawla,2016)
Sex	Dummy, Sex of household head(1=male,0=female)	±	(Christian,2019;Dawit,2018 ;Patrick,2007)
Marriage	Dummy,1=married,2=single, 3=divorced,4=widowed	+	(Christian,2019)
Age	Continuous, age of household head in years	±	(Christian,2019; Dawit,2018;Legesse & Chawla, 2016)
Land size	Continuous, total area of land owned by HH in hectares	+	(Abera, 2019; Dawit,2018; Legesse&Chawla,2016)
Education	Dummy, 0= illiterate, 1= basic education, 2= primary school (1-8), 3 =secondary school (9-12), 4 = TVET and above	+	(Abera,2019;Christian,2019 ;Dawit,2018)

Access to solar training	Dummy, 1= if household get training,0=otherwise	+	(Keriri,2013;Mbachu&Bizen,2017)
Access to media	Dummy,1=access to media,0=otherwise,	+	(Abera,2019)
Owning mobile phone	Dummy,1=if household has a cell phone, 0 if not	+	(Abera,2019)
Access to credit	Dummy,1=if household got access to credit, 0=otherwise	+	(Barzani,2021;Mishra,2018)
Prior information	Dummy,1=if the household has prior information/knowledge about solar energy, 0=otherwise	+	(Naomi,2014)

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Estimation of Monthly Average Daily Solar Radiation

The Angstrom equation is used to estimate daily global solar radiation of the three meteorological stations which have sunshine hour measurements. The annual average daily global solar radiation (Hcal) and extraterrestrial solar radiation (Ho) at Tsitsqa station has 6.18 and 10.09 kWh/m²/day respectively (Table 4.1). Tsitsqa stands out as the most suitable location for solar energy projects due to its higher average solar radiation and extended sunshine duration. The monthly average daily global solar radiation values (Hcal) at Tsitsqa station range from a low value of 5.37 kWh/m²/day in December to a high value of 7.07 kWh/m²/day in April indicating that the highest solar radiation occurs during the spring months. This study inline with instead of corresponds Natei *et al.*, (2022), who found that the Angstrom equations the monthly mean daily global solar radiation values it range from 4.3 to 7.6 kWh/m²/day and the annual mean daily global solar radiation was 6.2 kWh/m²/day in metehara station. The ratio of Hcal/Ho and S/So are useful for assessing solar energy potential. The Hcal/Ho ratio reflects the fraction of calculated daily global solar radiation compared to extraterrestrial daily global solar radiation peaking at 0.67 in January, November and December. Meanwhile, the sunshine to maximum sunshine ratio (S/So) decreases significantly during the rainy months of July and August indicating reduced solar energy availability.

The average S/So value has 0.7 demonstrating substantial sunshine availability throughout the year. The annual average sunshine hours (S) in Tsitsqa station were received 8.38 hour/day with maximum sunshine hours in February (9.39 hours/day) and minimum sunshine hours in July (5.86 hours/day) and the maximum possible sunshine duration (So) remains stable at ~12 hours/day. The regression constants (a and b) these are used in empirical models to estimate global solar radiation and also the average value was 0.35 and 0.42 respectively (Table 4.1), this result reflecting a stable relationship between sunshine hours and solar radiation. This result matches with Engidaw *et al.*, (2021), who found that the average values of a and b for East Gojjam station are 0.35 and 0.42 respectively, which are commonly used by different researchers in Ethiopia (Samuel & Bekele, 2014). The significance of high solar radiation during the dry season makes this location promising for solar energy harvesting. The seasonal variations emphasize the need for careful planning, particularly during the rainy season (July and August) affect solar radiation availability and the solar input decreases.

This result corresponds with Tegenu, (2019b), who found that the maximum value of the monthly average daily global radiation on a horizontal surface was estimated to be 6.96 kWh/m²/day in April. The minimum value of the monthly average daily global radiation was 5.42 kWhm⁻²day⁻¹ during December. The average global solar radiation that estimated by Angstrom empirical equation was 6.19 kWh/m²/day for Kombolcha station using sun shine hours from (2008-2017).

Table 4.1. Calculated monthly average daily global solar radiation and input parameters of monthly average daily global solar radiation for Tsitsqa station from (2009 – 2018).

Month	S	So	Hcal	Hest	Ho	a	b	Hcal/Ho	S/So
Jan	9.38	11.30	5.59	6.37	8.50	0.39	0.32	0.67	0.83
Feb	9.39	11.60	6.12	6.37	9.30	0.39	0.35	0.65	0.81
Mar	9.37	11.90	6.72	6.38	10.32	0.38	0.38	0.64	0.79
Apr	9.21	12.30	7.07	6.38	11.00	0.36	0.39	0.64	0.75
May	8.80	12.60	7.02	6.26	11.20	0.33	0.42	0.62	0.70
Jun	7.18	12.77	6.40	6.14	11.22	0.30	0.52	0.57	0.56
Jul	5.99	12.70	5.80	5.58	11.20	0.27	0.60	0.51	0.47
Aug	5.86	12.40	5.76	5.3	11.10	0.28	0.58	0.52	0.47
Sep	7.83	12.10	6.47	6.21	10.60	0.32	0.47	0.61	0.65
Oct	8.99	11.70	6.28	6.37	9.78	0.38	0.38	0.65	0.77
Nov	9.28	11.40	5.71	6.39	8.70	0.39	0.36	0.67	0.82
Dec	9.27	11.20	5.37	6.4	8.20	0.39	0.34	0.67	0.82
Avg	8.38	12.00	6.18	6.18	10.09	0.35	0.42	0.62	0.70

The annual average daily global solar radiation (Hcal) and extraterrestrial global solar radiation (Ho) for Lalibela station has 5.69 and 10.13 kWhm⁻²d⁻¹ respectively (Table 4.2). It is higher variability necessitate advanced technologies like hybrid systems to maximize efficiency and it shows slightly lower radiation levels than Tsitsqa. The daily global solar radiation (Hcal) values vary from 4.51 kWhm⁻²day⁻¹ (July) to 6.62 kWhm⁻²day⁻¹ (April) with the lowest values in the rainy season (July-August) show the lowest radiation likely due to high cloud cover during these months. This study inline with instead of corresponds Natei *et al.*, (2022), who found that the monthly mean daily global solar radiation value was 4.5 to 7.5 kWhm⁻²day⁻¹ in Dire Dawa site. The maximum measured global solar radiation has been recorded at this

station during the month of January and February. In July month both sites recorded their lowest measured and calculated solar radiation values in the coldest month. The ratio of H_{cal}/H_o reaches its maximum in December, January and February (0.65) but drops to 0.40 in July, indicating poor solar radiation utilization during the rainy season and S/S_o are follows a similar pattern peaking in January (0.82) and hitting its lowest in July (0.30). The regression constants (a and b), these are used in empirical models to estimate global solar radiation and also the average value was 0.32 and 0.48 respectively, this result suggests that higher variability and less predictable radiation trends. This study correspond with Natei *et al.*, (2022), the annual mean values of the regression coefficients (a and b) was 0.32 and 0.48, respectively for Addis Ababa sites. Lalibela has relatively lower compared to Tsitsqa, with the averages of H_{cal}/H_o and S/S_o has 0.57 and 0.61, respectively, reflecting reduced sunshine hours and radiation. The lower S/S_o values during the rainy season highlight the need for energy storage or supplementary power sources.

The annual average sunshine hours (S) Lalibela was received lower sunshine hours (7.31 hours/day) with the maximum sunshine hours in January (9.39 hours/day) and minimum sunshine hours in July (3.82 hours/day) and the maximum possible sunshine duration (S_o) remains stable at ~12 hours/day (Table 4.2). The significant seasonal drop in sunshine hours and radiation suggests the need for energy storage technologies in Lalibela, and it requires targeted interventions to improve solar energy capture. This study inline with instead of corresponds Girma, (2016), who found that the clearness index (H_{cal}/H_o) was ranges from 0.45 – 0.60 in Tepi site, which indicates the prevailing weather condition is partly overcast weather. According to Girma, (2016), the classifications on sunshine recorders vary, depending on site, season and dominant cloud formation. The latter can be roughly described by three ranges of relative daily sunshine hour (S/S_o), namely (1) Cloudy sky by ($0 \leq S/S_o < 0.3$), (2) Scattered clouds by ($0.3 \leq S/S_o < 0.7$) and (3) Fair weather by ($0.7 \leq S/S_o \leq 1.0$) (WMO, 2008). According to this classification the prevailing sunshine condition in Tepi site is mainly scattered clouds sky except during July to September when it can be considered as cloudy sky condition. The clearness index provides information on the level of availability of solar radiation at the surface of the earth as well as changes in atmospheric conditions (Adaramola, 2012; Jiang, 2009).

Table 4.2. Calculated monthly average daily global solar radiation and input parameters of monthly average daily global solar radiation for Lalibela station from (2009 – 2018).

Mont	S	So	Hcal	Hest	Ho	A	b	Hcal/Ho	S/So
Jan	9.39	11.38	5.63	5.91	8.62	0.39	0.34	0.65	0.82
Feb	9.26	11.62	6.09	6.05	9.45	0.38	0.36	0.65	0.80
Mar	8.15	11.94	6.33	5.99	10.38	0.34	0.43	0.61	0.68
Apr	8.13	12.28	6.62	5.99	10.98	0.33	0.45	0.61	0.66
May	7.38	12.56	6.34	5.72	11.13	0.31	0.50	0.57	0.59
Jun	5.50	12.7	5.49	5.05	11.11	0.30	0.64	0.49	0.43
Jul	3.82	12.64	4.51	4.16	11.13	0.22	0.70	0.40	0.30
Aug	4.29	12.35	4.84	4.13	11.08	0.23	0.67	0.44	0.35
Sep	5.89	12.06	5.53	5.01	10.65	0.28	0.57	0.52	0.49
Oct	7.78	11.75	5.88	5.79	9.83	0.33	0.45	0.60	0.66
Nov	8.63	11.44	5.52	5.88	8.82	0.36	0.38	0.63	0.76
Dec	9.44	11.31	5.45	6.17	8.34	0.39	0.33	0.65	0.84
Avg	7.31	12.00	5.69	5.49	10.13	0.32	0.48	0.57	0.61

The annual average global solar radiation (Hcal) and extraterrestrial daily global solar radiation (Ho) for Amdework the value was received 5.75 kWh/m²/day slightly higher than Lalibela and 9.79 kWhm⁻²day⁻¹ respectively (Table 4.3). The annual average sunshine hours (S) for Amdework enjoys moderate sunshine hours (7.93 hours/day) with highest sunshine hour in December (9.64 hours/day) and lowest value in August (4.10 hours/day) and the annual average maximum possible sunshine duration (So) remains stable at 12.01 hours/day. The daily global solar radiation (Hcal) values vary from 6.5 kWhm⁻²day⁻¹ (April) to 4.48 kWhm⁻²day⁻¹ (August). The minimum radiation occurred between June-August due to the peak period of the cloud covering the country in the rainy season. Generally, the higher value of solar radiation was obtained in the dry season. The regression constants (a and b) these are used in empirical models to estimate global solar radiation and also the average value was 0.34 and 0.44 respectively, this result shows moderate stability (Table 4.3).

This study corresponds with Natei *et al.*, (2022), who found that the annual mean values of the regression coefficients (a and b) was 0.34 and 0.43 respectively, for Mekele site. The monthly mean daily global solar radiation values it range from 3.2 to 7.6 kWhm⁻²day⁻¹ and the annual mean daily global solar radiation was 5.8 kWhm⁻²day⁻¹ for Addis Ababa station. The annual average of Hcal/Ho and S/So are slightly higher than

Lalibela but lower than Tsitsqa, averaging 0.59 and 0.67, respectively. The ratio of H_{cal}/H_o is highest in December (0.68) and lowest in August (0.43), S/S_o follows a similar trend, highest in December (0.86) and lowest in August (0.33). The significance of this station shows a balance between solar radiation potential and seasonal variability. Amdework has consistent the radiation levels make it a suitable location for medium-scale solar installations compared to Tsitsqa and Lalibela and the data suggest moderate reliability for solar power generation with less radiation loss during rainy months.

Table 4.3. Calculated monthly average daily global solar radiation and input parameters of monthly average daily global solar radiation for Amdework from (2009 – 2018).

Month	S	So	Hcal	Hest	Ho	A	B	Hcal/Ho	S/So
Jan	9.61	11.4	5.65	5.96	8.67	0.40	0.31	0.67	0.85
Feb	9.60	11.6	6.07	6.12	9.31	0.40	0.33	0.65	0.83
Mar	8.71	11.9	6.34	6.07	10.14	0.36	0.39	0.61	0.73
Apr	8.47	12.3	6.50	6.03	10.60	0.35	0.43	0.59	0.69
May	8.11	12.6	6.37	5.74	10.6	0.30	0.47	0.60	0.64
Jun	6.75	12.71	5.80	5.15	10.49	0.30	0.54	0.57	0.53
Jul	5.07	12.67	4.92	4.55	10.49	0.26	0.62	0.47	0.40
Aug	4.10	12.4	4.48	4.68	10.50	0.23	0.67	0.43	0.33
Sep	7.00	12.08	5.86	5.52	10.21	0.30	0.51	0.59	0.58
Oct	9.02	11.70	6.01	5.93	9.51	0.40	0.38	0.60	0.77
Nov	9.09	11.42	5.58	5.88	8.72	0.38-	0.35	0.64	0.80
Dec	9.64	11.3	5.41	5.94	8.3	0.4	0.31	0.68	0.86
Avg	7.93	12.01	5.75	5.63	9.79	0.34	0.44	0.59	0.67

The comparison between annual averages calculated (H_{cal}) and estimated (H_{est}) value of daily global solar radiation in Tsitsqa values align closely on match across all months and stations, confirming the validity of the models this indicates reliable model performance in this station. The accuracy of the estimation models ensures reliable predictions for solar energy projects. The solar energy potential of Tsitsqa offers the best solar potential followed by Amdework, then Lalibela. Therefore, the Angstrom equation is recommended for future research to estimate monthly average daily global solar radiation for the study area.

The maximum monthly average daily calculated and estimated global solar radiation occurred between in April ($7.07 \text{ kWhm}^{-2}\text{d}^{-1}$) and in November ($6.39 \text{ kWhm}^{-2}\text{day}^{-1}$) respectively. Generally, the higher value of solar radiation was obtained in the dry season. The result shows that the monthly average calculated and estimated daily global solar radiation on a horizontal surface for Tsitsqa station was between $5.37 \text{ kWhm}^{-2}\text{day}^{-1}$ (in December) to $7.07 \text{ kWhm}^{-2}\text{day}^{-1}$ (in April) and $5.3 \text{ kWhm}^{-2}\text{day}^{-1}$ (in August) to $6.39 \text{ kWhm}^{-2}\text{day}^{-1}$ (in November) respectively. The annual average value was calculated and estimated value to be $6.18 \text{ kWhm}^{-2}\text{day}^{-1}$. Tsitsqa is the most promising site and best location for solar projects with consistent high radiation and low error rates making it ideal for large-scale solar projects (Figure 4.1). The maximum monthly average daily calculated and estimated global solar radiation in Lalibela occurred between in April ($6.62 \text{ kWhm}^{-2}\text{day}^{-1}$) and in December ($6.17 \text{ kWhm}^{-2}\text{day}^{-1}$) respectively. The result shows that the monthly average calculated and estimated daily global solar radiation on a horizontal surface for Lalibela station was between $4.51 \text{ kWhm}^{-2}\text{day}^{-1}$ (in July) to $6.62 \text{ kWhm}^{-2}\text{day}^{-1}$ (in April) and $4.13 \text{ kWhm}^{-2}\text{day}^{-1}$ (in August) to $6.17 \text{ kWhm}^{-2}\text{day}^{-1}$ (in December) respectively. Lalibela shows higher deviations, with the annual average estimated daily global solar radiation value ($5.49 \text{ kWhm}^{-2}\text{day}^{-1}$) underestimating and annual average calculated daily global solar radiation value ($5.69 \text{ kWhm}^{-2}\text{day}^{-1}$) especially during high-variability months like April and July.

Lalibela station requires advanced technologies like concentrated solar power to overcome limitations during low-radiation periods (Figure 4.2). The maximum monthly average daily calculated and estimated global solar radiation in Amdework occurred between in April ($6.5 \text{ kWhm}^{-2}\text{day}^{-1}$) and in February ($6.12 \text{ kWhm}^{-2}\text{day}^{-1}$) respectively. The result shows that the monthly average calculated and estimated daily global solar radiation on a horizontal surface for Amdework station was between $4.48 \text{ kWhm}^{-2}\text{day}^{-1}$ (in August) to $6.5 \text{ kWhm}^{-2}\text{day}^{-1}$ (in April) and $4.55 \text{ kWhm}^{-2}\text{day}^{-1}$ (in July) to $6.12 \text{ kWhm}^{-2}\text{day}^{-1}$ (in February) respectively. The annual average value was calculated and estimated daily global solar radiation value to be 5.75 and $5.63 \text{ kWhm}^{-2}\text{day}^{-1}$ respectively. Amdework has suitable for balanced energy installations with moderate seasonal variability and the seasonal storage solutions or supplementary energy sources are necessary for Lalibela and Amdework during low-radiation months. According to the monthly average global horizontal solar radiation profiles the study sites receive the highest solar radiation in April and lowest solar radiation in July and August (Figure 4.3). This study matches with Engidaw *et al.*, (2021) who found that the monthly average daily global radiation value in Debre Markos varies between 3.97 and $5.88 \text{ kWhm}^{-2}\text{day}^{-1}$ for large solar energy projects. So, this result shows a good agreement for the assessed period

in the three stations. The direct and diffuse components of the global solar radiations values in the three stations are calculated for each and the result was shown seen in the below Appendix Table 3.

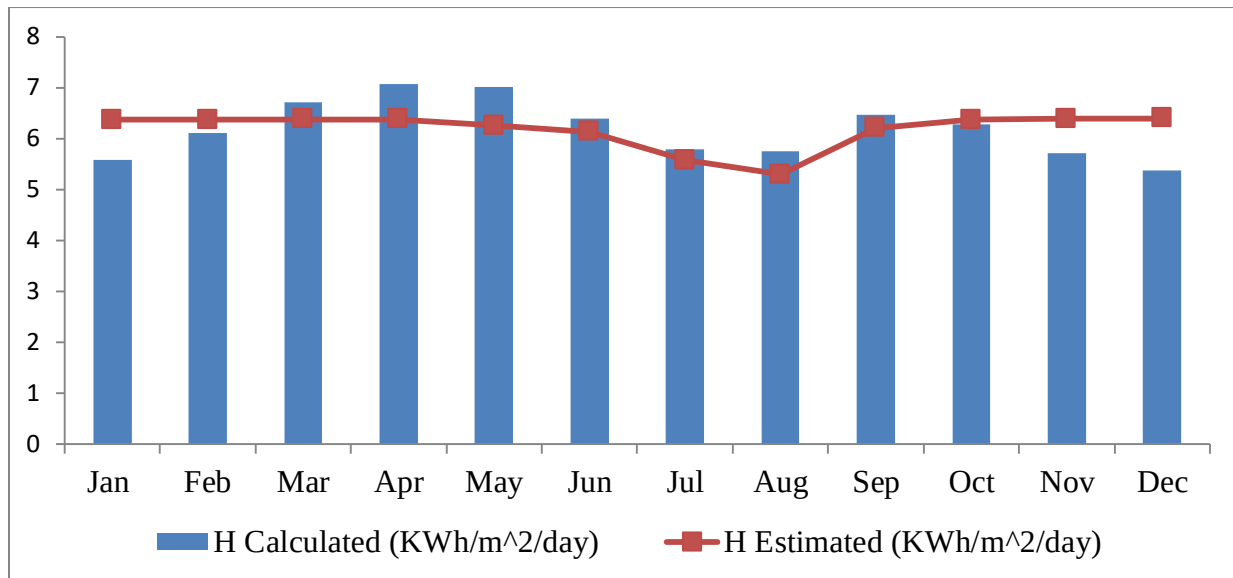


Figure 4.1. Comparison between calculated and estimated values of daily global solar radiation for Tsitsqa station from (2009-2018)

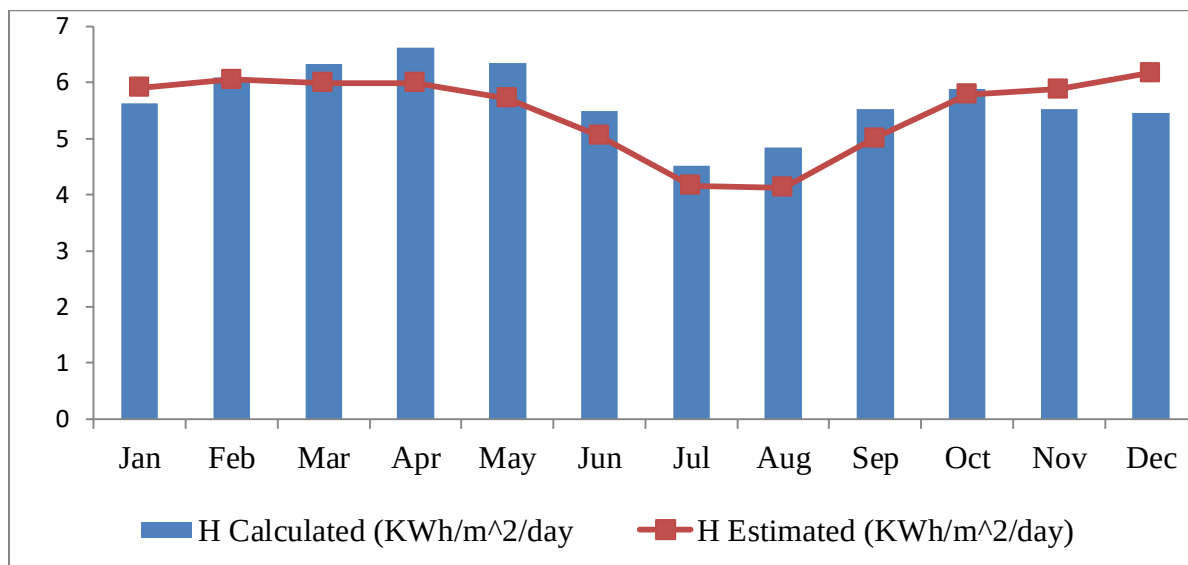


Figure 4.2. Comparison between calculated and estimated values of daily global solar radiation for Lalibela station from (2009-2018)

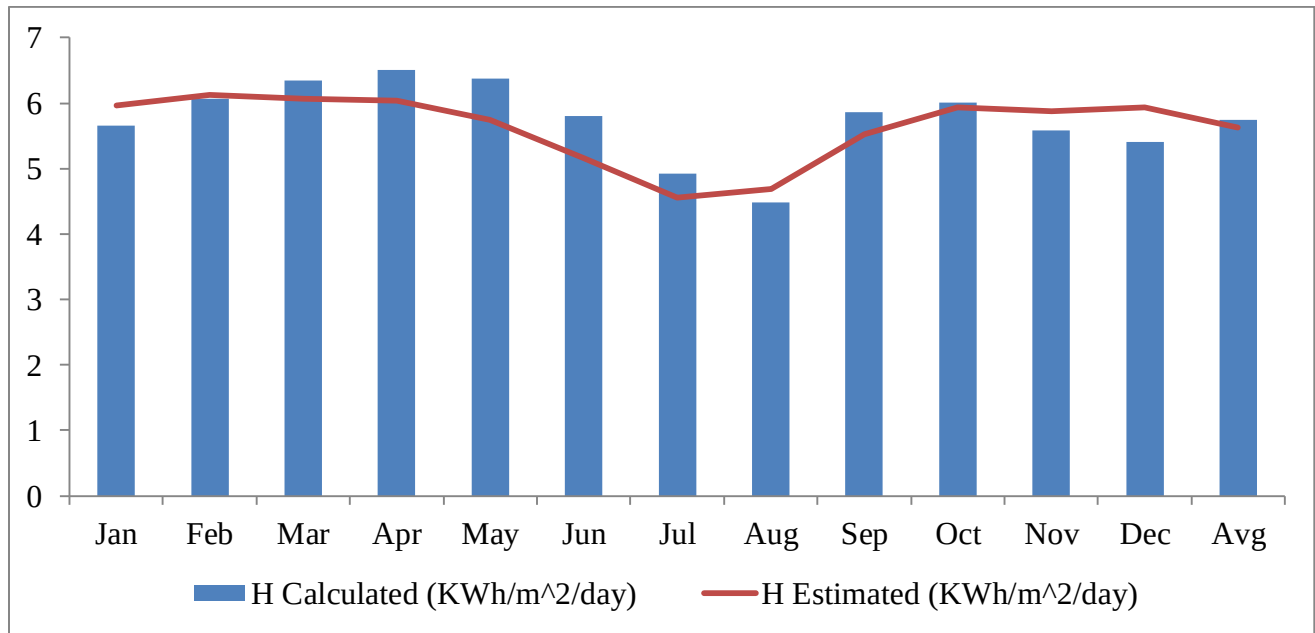


Figure 4.3. Comparison between calculated and estimated values of daily global solar radiation for Amdework station from (2009-2018)

The statistical parameters such as MBE, MPE and RMSE are used to determine the statistical test. According to Girma, (2016), the statistical test results it can be seen that for a good empirical equations the difference between calculated values of monthly mean daily global solar radiations are in favorable agreement with the estimated values of monthly mean daily global solar radiations should be approach zero. The low value of RMSE, MPE, MBE are desirable for a good model the systematic difference should approach zero. The validation of the proposed empirical equation to estimate solar radiation for Tsitsqa, Lalibela and Amdework sites (Table 4.4).

MBE (Mean Bias Error): This measures the average difference between calculated and estimated daily global solar radiation values to the number of observations in the year. A positive MBE indicates that on average the model is over predicting the observed value while a negative MBE indicates under prediction. A value close to zero suggests little systematic bias it indicates the bias in estimates (low is better). For Tsitsqa shows the MBE value has (0.006) which indicates a very small positive bias (predictions are slightly higher than observed values), this result was very close to zero, it indicates the model's reliability and it shows significant deviations in predictions. Tsitsqa has the lowest bias meaning its predictions are

nearly unbiased. Lalibela in MBE value has (0.050) suggests a systematic underestimation during some months, likely driven by unique local climatic phenomena. It has a lower positive MBE meaning the predictions tend to overestimate the observed values by about 0.050 units and also this result was close to zero. For Amdework, the MBE value has (0.056), meaning the model is slightly over predicting the observed values on average. However, the MBE is close to zero indicating that the predictions are relatively unbiased. The three stations Tsitsqa, Lalibela and Amdework has the mean bias error has a least value for a good fit and the value has close to zero (Table 4.4). In MBE Amdework has similar to Lalibela there is a slight overestimation but it is slightly higher than Lalibela bias. The MBE values are minimal, confirming minimal systematic bias in estimates.

This study matches with Natei *et al.*, (2022), who found that the MBE value has 0.0585 this value indicates close to zero and the model has a good fitness in Addis Ababa sites and also this study corresponds with Tegenu *et al.*, (2022), who found that the MBE value has 0.0212 as lowest value which has lowest deviation in Lalibela sites, the Angstrom equation is the best estimation of monthly averaged daily global solar radiation. This study on the contrary with Tegenu (2019b), the MBE value has 1.71 as highest value which has highest deviation in Kombolcha sites.

RMSE (Root Mean Square Error): It measures the average magnitude of prediction errors with lower values indicating better accuracy. The low RMSE (close to zero) is statistically accepted value. Tsitsqa station has the smallest RMSE value (0.363), implying better prediction accuracy and approach close to zero. Tsitsqa station has the most accurate predictions it indicates the least error between predicted and observed value with relatively small errors than other stations. For Lalibela station the RMSE value has (0.424) it indicates moderate error which has medium deviations than Amdework. The RMSE value has Lalibela (0.424) and Amdework (0.498) have slightly higher RMSE meaning their predictions are less accurate than Tsitsqa. This station the RMSE value has a bit higher suggesting that predictions are slightly less accurate compared to Tsitsqa. For Amdework station, the RMSE value has (0.498), this study suggests that lowest error but it could be acceptable depending on the scale of the data and the context of the analysis (Table 4.4).

Amdework has the highest RMSE value indicating the least accurate predictions among the three stations with more significant errors. The three stations Tsitsqa, Lalibela and Amdework has the root mean square error value has a least value for a good fit and the value has close to zero. This study corresponds with

Girma, (2016), who found that the RMSE value has 0.28 this indicates a least value has a good result in Tepi sites. The low RMSE and MBE value further validate the accuracy of predictions reducing financial and technical risks for solar projects. This study matches with Tegenu *et al.*, (2022), who found that the RMSE value has 0.4010 as lowest value which has lowest deviation in Lalibela sites and also this study consistent with Natei *et al.*, (2022) the RMSE value has 0.5557 in Metehara sites, this results has a goodness of fit and approach close to zero, it indicates the Angstrom equation is highly recommended to estimate daily global solar radiation.

MPE (%) (Mean Percentage Error): This measure average of the percentage errors between calculated and estimated daily global solar radiation values. It helps to understand the error in relative terms making it easier to compare models or stations with different scales of values. The value between -10% and +10% is considered as acceptable value. In Tsitsqa station the MPE (%) value has (-2.579%) which suggests a small underestimation in predictions (about 2.579% lower than observed values). The negative value indicates a slight underestimation in predictions. In Lalibela the MPE has (0.583%) meaning predictions are slightly overestimated by 0.583% on average. A small positive MPE means predictions are generally overestimated by about 0.583% compared to observed values while Amdework, MPE value has (0.533%) as a test of goodness of fit and relatively balanced predictions. The three station in Tsitsqa, Lalibela and Amdework has in mean percentage error value has a good result and this result has between -10% and +10% is considered as acceptable value (Table 4.4).

The significance of the statistical analysis supports the use of these regression models for solar energy prediction and planning. This study corresponds with Tegenu, (2019b), who found that the MPE (%) value has 0.22% as a taste of goodness of fit since MPE has a least value for a good fit in Kombolcha sites. In statistical test validation always, the least is accepted. This study matches with Natei *et al.*, (2022) who found that the MPE value has 0.596 in Metehara site, -1.8241 in Nekemte site and -1.0889 in Gondar site, in all station the MPE (%) value has between -10% and +10% it indicates a least value has a good fitness.

Table 4.4. The statistical indicators for the three stations from (2009 - 2018)

Station	MBE	MPE	RMSE
Tsitsqa	0.006	-2.579	0.363
Lalibela	0.050	0.583	0.424

Amdework	0.056	0.533	0.498
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4.2. Solar Energy Potential Assessment

The overall average of the three stations has highest global solar radiation for the entire year was $6.73 \text{ kWhm}^{-2}\text{day}^{-1}$ in April and the lowest value was $5.03 \text{ kWhm}^{-2}\text{day}^{-1}$ in August which is calculated from the averages of the three stations across in the month (Table 4.5). The seasonal trends there is a clear seasonal pattern in the data solar energy potential at these locations is clearly highest solar radiation being in the spring months of (March-May). These months would be ideal for solar energy generation and the lowest solar radiation occurs in the summer months (June-August), so strategies for optimizing energy production during these months could include using energy storage systems or other renewable energy sources. Tsitsqa station consistently has the highest radiation, which could be due to its geographical location, altitude or other local environmental factors. This study matches with Engidaw *et al.*, (2021), who found that according to the models, the annual mean daily global horizontal radiation for Debre Markos, Debrewerk, Mota, and Yetnora is $5.88 \text{ kWhm}^{-2}\text{day}^{-1}$, $6.52 \text{ kWhm}^{-2}\text{day}^{-1}$, $6.28 \text{ kWhm}^{-2}\text{day}^{-1}$, and $6.31 \text{ kWhm}^{-2}\text{day}^{-1}$, respectively, which is actually a very good solar energy potential.

This result matches with Tegenu, (2019b), who found that the highest solar radiation in spring season than summer for many regions due to some factors such as cloud cover, atmospheric conditions, and the angle of sunlight. This result consistent with Natei *et al.*, (2022), who found that the estimated monthly average daily solar radiation in Ethiopia ranges from 3.45 to $7.47 \text{ kWhm}^{-2}\text{day}^{-1}$, with an annual average of $5.83 \text{ kWhm}^{-2}\text{day}^{-1}$. According to Girma, (2016), earlier research validated the Angstrom relations for Ethiopian locations and highlighted the importance of accurate regression coefficients for precise estimation. These findings underscore Ethiopia's significant solar energy potential and can inform future renewable energy initiatives in the country.

Table 4.5. Calculated global solar radiation on a horizontal surface for the three meteorological stations from (2009 - 2018)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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Tsitsqa	5.59	6.12	6.72	7.07	7.02	6.4	5.8	5.76	6.47	6.28	5.71	5.37
Lalibela	5.63	6.09	6.33	6.62	6.34	5.49	4.51	4.84	5.53	5.88	5.52	5.45
Amdework	5.65	6.07	6.34	6.5	6.37	5.8	4.92	4.48	5.86	6.01	5.58	5.41
Avg	5.62	6.09	6.46	6.73	6.58	5.9	5.08	5.03	5.95	6.06	5.6	5.41

Finally, the calculated annual average daily global solar radiation values for the 3 stations are imported and interpolated to draw a solar map showing distribution of solar radiation in zone and neighboring station using Arc-GIS as seen below. As a result, the spatial analysis and mapping show a significant variation in monthly mean daily global solar radiation in Waghimra zone (Tsitsqa and Amdework station) and nearly station (Lalibela station) ranging from the highest estimated global solar radiation is $6.32 \text{ kWhm}^{-2}\text{day}^{-1}$ while the lowest global solar radiation is $5.12 \text{ kWhm}^{-2}\text{day}^{-1}$ this indicates that the study area has high solar energy potential. The contour lines show area with nearly the same amount of annual average solar insolation (Figure 4.4).

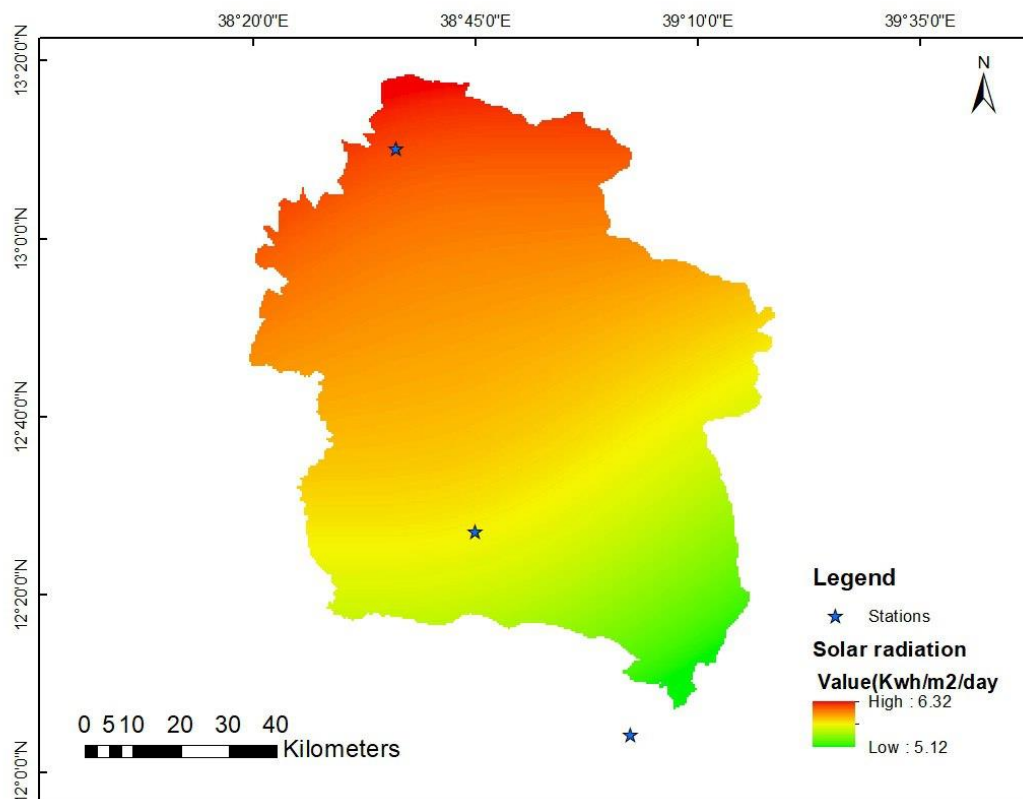


Figure 4.4. Solar energy potential distribution map of the three stations

4.3. Factors Affecting Adoption of Solar Energy Technologies

4.3.1. Household solar energy adoption status

The survey sampled respondent household heads were asked if they had installed solar energy technology in their household. Their responses highlighted it indicates 26.65% of the respondents in the three kebeles had installed solar energy technology in their households, while the remaining most of respondents 73.35 % of the household had not installed solar energy technology in their home. The majority percent of the respondent had not adopted solar energy technology. This implies that in Ziquala district has low adoption rate of solar energy technology in Adisu Frie, Nika Tederaji and Netsanet Melkam kebeles. A total sample of 349 households participated in the study area. Which has 91.4% were male and 8.6% were female headed households. From 93 households were adopted solar energy technology (21 HH from Adisu Frie, 34 household from Nika Tederaji and 38 household from Netsanet Melkam kebele households) and 256 household were non-adopted solar energy technology (61 household from Adisu Frie, 100 household from Nika Tederaji and 95 household from Netsanet Melkam kebele households). As shown in figure 4.5, out of the total 349 sample households, 93 households (26.65%) own at least one type of solar PV system or lantern primarily for lighting basic electricity (solar-electrified).

This may suggest that three districts in rural household in the study area were very few accesses to solar light. In terms of geographic distribution, however, a variation exists in the adoption of solar PVs between the three districts. The highest rate of uptake of the solar PVs was observed in Netsanet Melkam kebele with 28.57% of household's solar adopters and the lowest in Nika Tederaji and Adisu frie kebele with 25.37% and 25.61 % solar adopters' households respectively. One possible explanation for this conspicuous variation is that Netsanet Melkam kebele, located in close distance to the Tsitsqa town, has better access to the solar PV supply chain with a relatively well-established market that facilitated the diffusion of the technology in the district. The main reason for the preference of many solar users to Pico PV (solar lantern) solutions as explained by the household heads surveyed and focus group discussion (key informants) is the high cost of larger capacity SETs and conversely, the affordability, ease of portability, and simplicity of use of the Pico PV systems.

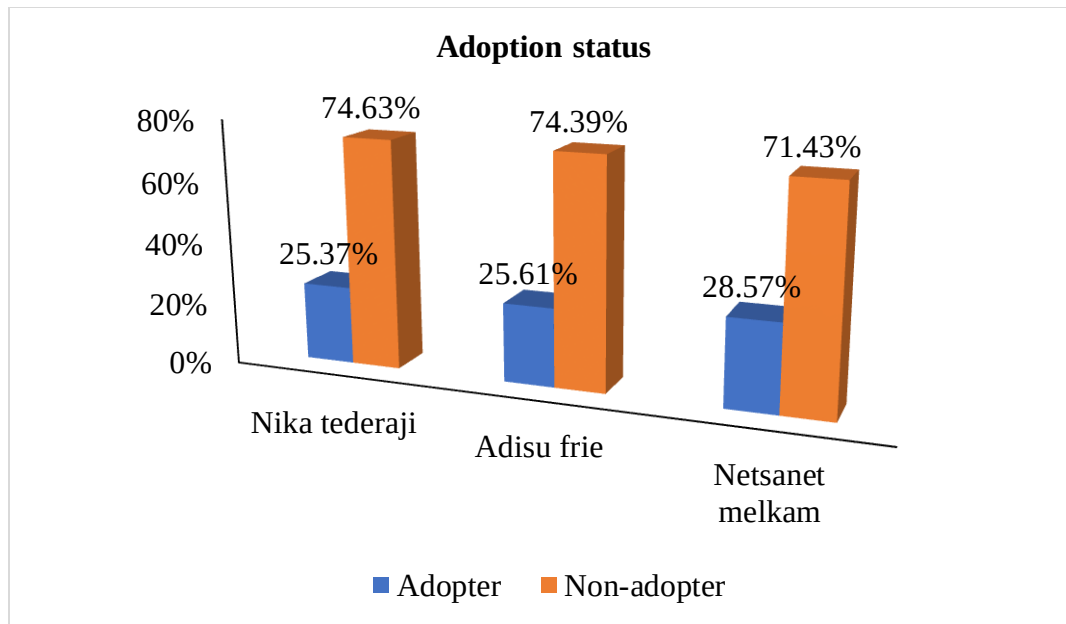


Figure 4.5. Household adoption status of solar products in the study district

These study results reveal that the majority of non-for lighting their homes solar adopters have been using wood for lighting their homes which can lead to series health and environmental damage. Additionally, non-solar adopter was asked the reason they still have not installed solar technology in their households. As clearly shown the below figure 4.6, from the response, 40% of the respondents' states that they could not afford to buy solar products, this reflects the high upfront cost of purchasing and installing solar systems, including panels, inverters, batteries, and other necessary components. While solar energy can lead to long-term savings the initial financial barrier remains a challenge especially for low- and middle-income households. This result indicates to address this issue, governments, NGOs and private sector players may need to continue offering subsidies, rebates, or low-interest loans to help reduce the upfront cost of solar adoption, 30% of respondents indicated that they were not awareness of solar energy technology or its benefits. This suggests that there is a knowledge gap in many communities about how solar power works, its potential savings, and environmental benefits and many people may not fully understand how solar panels can reduce electricity bills, or not aware of the financial incentives available in their area.

This result indicates a clear need for educational campaigns and outreach programs that target communities to raise awareness. These programs can include information about the technical aspects of solar technology, as well as guidance on how to apply for subsidies or financing options and public awareness initiatives

could come from government bodies, private companies, or even local non-profits. Approximately 30% of respondents reported a lack of credit facilities, which is closely related to affordability concerns. Many individuals do not have access to financing options that would enable them to pay for solar installations in installments or through loans. This underscores the importance of expanding access to credit facilities to enhance solar adoption. Financial institutions could collaborate with solar providers to create more favorable financing plans, while governments could contribute by offering subsidized loans or loan guarantees to mitigate risks for these institutions. The findings suggest that the primary reasons for the limited adoption of solar energy technology among households are financial constraints, lack of credit, and insufficient awareness of available products (Barzani, 2021; Dawit, 2020). This situation highlights the challenges faced by rural areas in Ethiopia where poverty and resistance to new technology hinder progress. To better understand the major constraints to the efficient use and widespread adoption of solar lighting systems, solar-user household heads were surveyed regarding the problems and barriers they encountered through closed-ended questions.

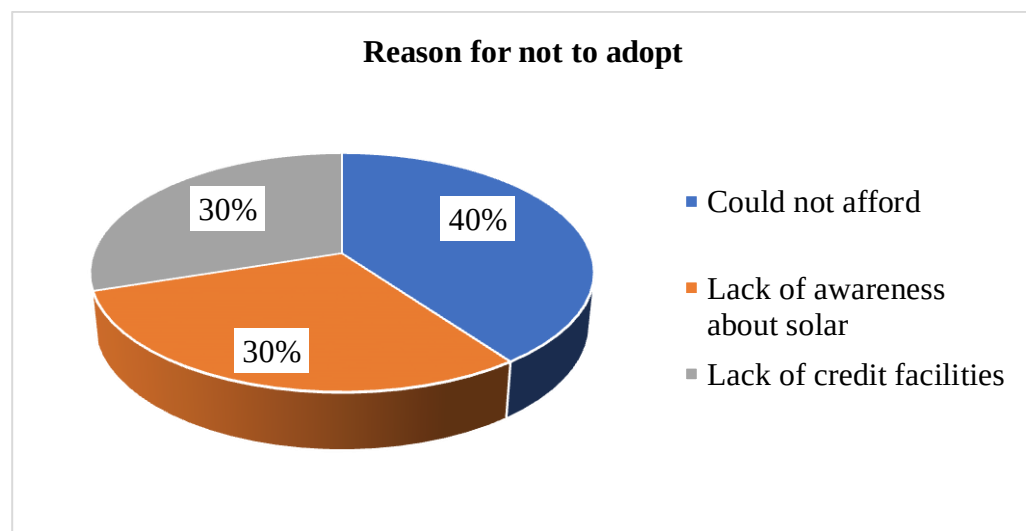


Figure 4.6. Reason not to adopt

4.3.2. Socio-demographic factors

Different characteristics of households like sex of the household head, marital status of household head, access to credit, educational level, training access, media access, own cell phone, and prior information were given due consideration (Table 4.6).

Sex of household head: The chi-square test was conducted to examine the association between sex and adoption status. About 89.25 % and 10.75% of households who adopted solar energy technology were male and female respectively, which is relatively more compared to non-adopter households which are about 92.19 % and 7.81% households who not adopted solar energy technology were male and female respectively (Table 4.6). This implies that most houses are dominated by male household heads. This might be because most rural households in Ethiopian are known to be a male dominated in their characteristics. The Chi-square test indicates 0.75 values with resulting in a p-value of 0.386 ($p \geq 0.05$). This shows there is no significant association between sex of respondents and decision to adopt SET. This finding is consistent with some studies where the sex differences were not significant in adoption of certain innovations. For example, in the adoption of solar energy sex often has a minimal impact with both males and females showing similar adoption patterns. However, other studies have found sex differences particularly in contexts where women's roles in household energy decisions are more pronounced.

Marital status of household head:- The respondents were asked about their marital status. The responses of marital status of the household head indicates that the majority of respondent adopters were (86.02%) of household head were married, while 3.23%, 6.45% and 4.3% of them were single, divorced and widowed respectively. Another non-adopter respondents were (84%) of household head were married, while 1%, 8% and 7% of them were single, divorced and widowed respectively. This implies that most of the household head in three kebeles are married. The Chi-square test indicate 3.843 value with resulting in a p-value of 0.279. This shows there is no significant association between the marital status of respondents and the adoption status ($P \geq 0.05$). In solar energy adoption, marital status can sometimes play a role, especially in cases where joint decision-making by couples is involved. Studies have shown that married couples may be more likely to invest in solar energy due to combined financial resources and shared decision-making.

Educational level of house hold head- In the same way concerning educational level the majority of respondents had 72.5% were (23 adopters and 230 non-adopter) of the household heads were illiterate who couldn't read and write. The other 18.1% were (43 adopter and 20 non-adopter), 6.3% were (16 adopter and 6 non-adopter), 2.3% were (8 adopter) and 0.9% were (3 adopter) were basic education, primary education (1-8), secondary education (9-12) and TVET and above the level of education respectively (Table 4.6). This study corresponds with Barzani, (2021), who found that in the model this variable is included as literate (households who attended formal education) and illiterate (households who didn't attend formal

education). This implies the level of education is a major factor affecting the adoption of solar energy technology. The analysis indicated that more educated households' heads were solar energy technology adopters compared to non-adopters. The households who adopted solar energy technology had more educated household heads. The chi-square test value was 145.04 with the P value was 0.00 for this result shows that there is a statistical association between the education level of household heads and SET adoption status ($p < 0.01$).

Access to credit: - The association between credit access and adoption status was assessed. The minority (13.75%) of the households had the opportunity of getting credit access were 25 adopters and 23 non-adopters, while the remaining most of the respondents (86.25%) who had no credit access were 68 adopters and 233 non-adopters. The Chi-square test value was 18.42 with the p-value was 0.00 for this result shows that there is a statistical association between credit access and SET adoption status ($p < 0.01$). Similarly, access to credit has been a crucial factor in the adoption of solar energy systems where financing options can significantly influence homeowners' decisions. Studies have highlighted that the availability of credit or subsidies for solar energy systems greatly increases adoption rates as it reduces the financial burden associated with initial costs.

Prior information/knowledge: - Out of the total sample, 3.72% of them reported that they have prior information about the SET whereas 96.28% of respondents confirmed that they have no prior information about the SET so far. This study on the contrary with Legesse & Chawla, (2016), who found that the majority (84.3%) of respondents have information about the benefits of renewable energy sources such as solar and biogas while 15.7% of them have no information in the Ambo district. The chi-square test was 8.41 with resulting in a p-value of 0.004. The chi-square test showed that there is a statistical association between prior information/knowledge and the adoption status ($p < 0.01$).

Access to solar training: Training impact on adoption status was evaluated through the chi-square test. The observed frequencies for those with training access were 6 adopters and 3 non-adopters, about 2.58% of the respondents received informal /awareness creation/ training on how to utilize SET products in their homes, the remaining for those without training access the frequencies were 87 adopters and 253 non-adopters about 97.42% of respondents replayed that they had never received neither formal nor informal training regarding the solar energy technology. The training was delivered by the energy office of the districts and solar energy product distributor's /seller/ jointly. The chi-square statistic was 7.569 with

resulting in a p-value of 0.006. This shows a significant association between training and adoption status ($p < 0.01$). Awareness and understanding of solar energy technology, installation procedures and maintenance can enhance confidence and willingness to invest in solar energy systems.

Media access:- The role of media in influencing adoption status was also analyzed. The observed frequencies for media users were 21 adopters and 15 non-adopters, about 10.32% of respondents had access to media while the remaining non-media users had 72 adopters and 241 non-adopters, about 89.68% of respondents had no access to media. This result on the contrary with Barzani, (2021), regarding media access 60.52% of the total respondents had access to media while the remaining 39.48% had neither radio nor TV in East Harerge zone. The chi-square statistic was 20.62 with the p-value was 0.00. This indicates that there is a statistical association between media access and SET adoption status ($p < 0.01$).

Own cell phone: - The effect of owning a phone on adoption status was tested. The minority 18.91% of the households owning cell phone were 30 adopters and 36 non-adopters for those who own a phone and the majority 81.09% of the households do not owning cell phone were 63 adopters and 220 non-adopters for those who do not own cell phone. The chi-square statistic was 14.73 with the p-value was 0.00. This suggests a significant association between owning a phone and SET adoption status ($p < 0.01$). In solar energy adoption having access to communication technologies (e.g., smart phones) can facilitate the dissemination of information, online research and access to support services, thus potentially increasing adoption rates.

Table 4.6. Descriptive statistics of adopters and non-adopters on categorical /dummy variables/

Explanatory Variable	Category	Adopter (93)		Non-adopter (256)		Total (349)		Chi ² test	P-value
		No	%	No	%	No	%		
Sex	Male	83	89.25	236	92.19	319	91.40	0.75	0.386
	Female	10	10.75	20	7.81	30	8.60		
Marital status	Single	3	3.23	2	0.78	5	1.43	3.843	0.279
	Married	80	86.02	216	84.38	296	84.81		
	Divorced	6	6.45	20	7.81	26	7.45		
	Widowed	4	4.30	18	7.03	22	6.30		
Educational	Illiterate	23	24.7	230	89.8	253	72.5	145.04	0.00**

Level of HH	Basic education	43	46.2	20	7.8	63	18.1		*
	Primary school (1-8)	16	17.2	6	2.3	22	6.3		
	Secondary school (9-12)	8	8.6	0	0	8	2.3		
	TVET and above	3	3.2	0	0	3	0.9		
Credit accessibility	Yes	25	26.88	23	8.98	48	13.75	18.42	0.00**
	No	68	73.12	233	91.02	301	86.25		*
Training access	Yes	6	6.45	3	1.17	9	2.58	7.569	0.006*
	No	87	93.55	253	98.83	340	97.42		**
Own cell phone	Yes	30	32.26	36	14.06	66	18.91	14.73	0.00**
	No	63	67.74	220	85.94	283	81.09		*
Media access (radio or TV)	Yes	21	22.58	15	5.86	36	10.32	20.62	0.00**
	No	72	77.42	241	94.14	313	89.68		*
Prior info/knowledge	Yes	8	8.60	5	1.95	13	3.72	8.41	0.004*
	No	85	91.4	251	98.05	336	96.28		**

Note: *, ** and *** show significance levels at 10%, 5% and 1%, respectively.

Source: Own computation results based on survey data, 2024.

Different characteristics of sample households were compared to see if there are significant differences between solar energy adopter and non-adopter groups. These include annual income, land holding size and age of household head (Table 4.7).

Annual household income: The mean annual income of the sampled household heads was 36941.63 with a standard deviation of 17867.17. The minimum and maximum annual incomes were 10000 and 76100 birrs. The mean annual income of the household heads was 43482.58 with (SD=16726.80) and 34565.42 with (SD =17704.72) for solar energy adopter and solar energy non-adopter households respectively. The statistical test of the mean annual income of the household heads shows that there was no statistically significant difference between solar energy adopter and solar energy non-adopter households. The analysis showed that the mean annual income of SET adopters (43482.58 birr) was greater than the mean annual income of non-adopters (34565.42 birr). The p- value for income was 0.411 indicates that there is no significant because ($P \geq 0.05$) the t test of mean difference between adopters and non-adopters of the solar

energy system value has 4.221. The average gross annual cash income per household was estimated to be Eth. birr (ETB) 36941.63 roughly (in 2024) (Table 4.7).

Age of household head: The average age of the household head from the sampled households was 58.66 years, with a standard deviation of 16.98 years. The ages varied significantly ranging from a minimum of 20 years to a maximum of 89 years. For households that adopted solar energy, the mean age of the household heads was 41.10 years with (SD = 7.60) while for non-adopters, it was 65.05 years with (SD = 14.81). Statistical analysis revealed a significant difference in the mean educational levels of household heads between solar energy adopters and non-adopters. The p-value for the age of household head was 0.00 indicates that there is significant because ($P < 0.1$) while the t test of mean difference between adopters and non-adopters of the solar energy technology value was -14.89. Interestingly, the household heads of solar energy adopters were relatively younger with an average age of 58.66 years compared to the non-adopters who had an average age of 65.05 years (Table 4.7).

Land holding size: - The landholding size per household among the sampled households varied significantly ranging from a minimum of 0.00 hectares to a maximum of 2 hectares. The average cultivated land for these households was 0.77 ± 0.36 hectares. For solar energy adopters the mean cultivated land was 0.91 hectares with (SD = 0.28), while for non-adopters it was 0.72 hectares with (SD = 0.37). In terms of assets own which serve as a proxy for wealth, the results indicated that adopter households had a larger average land size of 0.91 hectares compared to non-adopters who averaged 0.72 hectares. However, the total landholding size showed no significant variation between solar energy adopters and non-adopters as indicated by a p-value of 0.00. This suggests that there is statistically significant difference ($P < 0.1$) in mean landholding size between the two groups regarding the adoption of solar energy technology while t test of mean difference between adopters and non-adopters of the solar energy technology value was 4.376 (Table 4.7). According to Chukwuebuka *et al.*, (2019), land holding sizes in Ethiopia have been decreasing due to population growth and the conversion of forested areas to agricultural land.

This study matches with Stein & Mesfin, (2020) who found that a study in Tigray region found that average farm size declined from 1.15 ha in 1998 to 0.90 ha in 2016 with increasing inequality in land distribution. Land rental markets while allowing some adjustment in operational holding sizes are limited by factor market imperfections and tenure insecurity. Regional differences in land use changes are observed with water availability playing a crucial role. In water-sufficient areas cropland has expanded at the

expense of grazing land while semi-arid regions show minimal changes due to water limitations. Gender disparities in land holdings persist with male-headed households having 27-35% more land than female-headed households although female landholding share was 48.8% in Tigray in 2016 (Stein & Mesfin, 2020).

Table 4.7. Descriptive statistics and test of mean differences of adopters and non- adopters on continuous /discrete variables

Explanatory variable	Adopter		Non-adopter		T-test	P-value
	Mean	Std.Dev	Mean	Std.Dev		
Annual HH income in birr	43482.58	16726.12	34565.42	17704.71	4.221	0.411
Age of HH in year	41.10	7.597	65.05	14.81	-14.89	0.00***
Land holding size in hectare	0.906	0.276	0.72	0.373	4.376	0.00***

Note: *, ** and *** show significance levels at 10%, 5% and 1%, respectively

Source: Own computation results based on survey data, 2024.

4.3.3. Econometric results of determinants of household solar energy adoption status

The response variable was either adopting or not adopting the solar energy system. Those households who had solar energy technology were considered as adopters and those who had not considered as being non-adopter. According to Maddala, (2012), the correlation value of 0.75 and above indicates a stronger relationship between dummy independent variables. Therefore, marital status is excluded from the model to reduce its effect on the regression estimate. The Nagelkerke R^2 (0.817) indicates a strong proportion of variance explained by the model and suggests the model explains 81.7% of the variance in solar energy adoption. The Cox & Snell R^2 (0.557) it indicates a reasonable fit and -2 Log Likelihood (120.87) used to assess overall model fit smaller values indicate better fit. The Hosmer - Lemeshow test ($p = 0.257$) is applied to estimate the overall model fit. Since the p-value is greater than statistically significant ($p < 0.05$) the estimated model has an adequate fit for the purpose (Table 4.8).

For this study, the correct model predictions for adopters and non-adopters were 81.7% and 90.6% respectively and the overall correct model prediction was up to 88.3%. The total of 10 explanatory variables included in the model, 7 of them were found to have a statistically significant effect on households' decision to adopt SET. These variables include; Income level of household, credit access, age of household, educational status of households' head, own cell phone, prior information/knowledge and training access about SET (Table 4.8).

Income level of household: The income of the household is found to be one important factor in households' decision to adopt solar energy technology. The study showed that the income of households has a positive and statistically significant ($P < 0.1$) effect on solar energy technology adoption. The odd ratio of the binary logistic regression model indicated that as income of household increase by one birr the probability of adopting a solar energy technology increase by a factor of 2.576. The Walder statistics (13.538) also indicated the strong association between income and SET adoption (Table 4.8). As the income of the household increases, the probability of taking up solar energy technology increases because it creates a better financial ability to pay for the installation of solar energy technology. This implies that as households become economically strong their propensity to invest in renewable energy technology also increases. This result is consistent with Dawit, (2018) who found that as the income of the household become higher, their purchasing power increase and as the same time their demand for solar energy technology becomes higher.

It also agrees with De Groote *et al.*, (2016), who argued that the income of households is important and has a significant effect on solar energy technology installation. Generally, the observed positive correlation in the model estimation indicates the fact that when households got richer, they can adopt new technologies such as solar. In other word, households shift towards using solar energy technology as their income increases. This means that the policies which augment household income (i.e., reduce poverty) may be a viable strategy to promote solar energy technology adoption by rural households. The findings of this study are generally in agreement with the relevant literature, as the findings point to an increase in the likelihood of household solar energy technology adoption with an increase in household wealth such as with income and land asset (De Groote *et al.*, 2016; Rahut *et al.*, 2018; Smith & Urpelainen, 2014).

Access to credit: The result indicated that the sample households, access to credit was found that it was statistically significant ($p < 0.1$) and negatively influence on the decision of household to adopt solar energy

technology because due to lack of credit accessibility. Other variable remaining constant the odd ratio of logistic regression indicated that solar energy adoption of households those are have not access to credit are higher by a factor of 0.268 ($P < 0.1$) as compared to households those access to credit. The Wald statistics (of 16.872) also indicated that there is a strong statistical association between access to credit and SET adoption (Table 4.8). This finding is contrasted with Mills & Schleich, (2008), who found that theoretically, as it is expected that households with access to credit services are expected to have a higher probability of adopting solar energy technology. This is because lucrative investment can be impossible especially for the low-income households due to liquidity constraint. This result is a negative relationship between the adoption of a solar energy technology and access to credit.

Age of household head: The age of household was found to have a significant ($p < 0.1$) and a negative effect on solar energy technology adoption by Ethiopian rural households. The Wald statistics (of 18.23) also indicated that there is a strong statistical association between the age of household and SET adoption. This means that the probability of older household heads to adopt solar energy technology is more than their younger counterparts or the probability of younger household's head to adopt solar energy technology is lower than older counterparts. Other explanatory variable remains constant as the age of the household head increases by 1 year, the odds ratio of solar energy technology adoption increases by a factor of 0.093 (see Table 4.8). The finding is in contrasted with some of the previous studies which indicated that younger people are more willing to pay for renewable energy because of higher awareness of the environmental benefits (De Groote *et al.*, 2016) and correspond to some of the previous studies which indicated that older people are more willing to pay for renewable energy because of higher awareness of the environmental benefits (Christian, 2019; Dawit, 2018; Legesse & Chawla, 2016).

This result correspond with Barzani, (2021), who found that the younger household heads are less likely to adopt solar energy technology compared to older ones. That means it has a negative influence on the household's willingness to adopt a solar energy technology. The plausible explanation for the positive effect of the household-head age may relate to the fact that younger household heads may be wealthier as they own more productive resources (e.g., land) and likely able to invest in renewable energy technologies.

Prior information/knowledge: The result of this study shows that prior knowledge or awareness of households has a negative influence on household decision to adopt the solar energy technology at a statistically significant level ($P < 0.1$). The odd ratio showed that the adoption of respondents who have no

prior knowledge or information about the solar energy technology is higher by a factor of 0.212 ($P < 0.05$) as compared to households who had prior information about solar energy technology. The Wald statistics (of 7.076) also indicated that there is a strong statistical association between prior knowledge and SET adoption (Table 4.8). This result contrasted with Naomi, (2014), who found that this implies that households who have accumulated prior knowledge or awareness are more likely to adopt SET. However, households who have low awareness or knowledge level, tend to use risky and low efficient energy sources such as kerosene. This is also related to that if they didn't have information about the bad and good side of the new technology, they become reluctant about whether to accept or reject it. This result is a negative relationship between the adoption of a SET and awareness/ knowledge about the solar energy technology.

Educational level of household head: According to the model estimation, education level was found to have significant and positive relationship with solar energy adoption decision at 10% level of significance ($p < 0.1$). The education level of household heads is one of the key factors determining households' willingness to adopt SET. The odd ratio indicated that other explanatory variable remain constant literate household heads are more likely to adopt solar energy higher by the factor of 26.923 compared to illiterate household heads (Table 4.8). Education improves household awareness and expands the opportunity for employment and thus a higher education attainment by the household head is expected to increase the likelihood of solar energy technology adoption. This finding is consistent with the relevant theory because more educated heads may have a better knowledge of the benefits of solar energy technology. This is because the more educated the household heads are more; they can be in agreement regarding the adoption of solar energy technology. In general, the plausible explanation for the positive effect of education relates to an increase in the awareness of educated household heads regarding the environmental, health, economic and societal welfare benefits of solar energy technology adoption.

The finding is consistent with the findings of previous studies. For instance, a study found that people with a higher educational status or highly educated people are more willing to pay for renewable energy (Yibeltal & Adaramola, 2021). This may also relate to an increase in awareness of educated individuals regarding pro-environment policies including a higher willingness to pay for renewable energy technologies (Dawit, 2020). With an increase in the education levels of the household head there is also an increase with the level of awareness of the household regarding clean energy services a high level of education is also associated with an increase in the household earning capacity and this leads to the generation of income to invest in solar energy equipment (Rahut *et al.*, 2018). The result also reveals the

fact that households who have no formal education are less likely to adopt solar energy compared to their counterparts. Better exposure to education makes households to be more flexible to know, understand, and aware of new renewable energy technologies and also their health and environmental benefits. This result is consistent with Dawit, (2018), who revealed that education increases households' awareness regarding the health, environmental, economic, and societal relevance of the solar energy. This clearly shows that in addition to its role to increase awareness, advancing in education level increases households earning capacity that endures their capacity to invest in clean energy technologies such as solar. The other study added that as households acquire a better education level, they are more likely to be more informed about the adoption of other best sources of energy (Gitone, 2014). Generally, educated people are fast to improve their awareness level, which leads them to support pro environmental policies for which they are willing and are committed to pay for renewable energy technologies compared to non-educated (Dawit, 2018; Gitone, 2014).

Access to solar training: Access to training found to have a negative influence on solar energy technology adoption at a statistically significant level ($P < 0.05$). The odd ratio indicated that the adoption of respondents who haven't been accessed with training is higher by the factor of 0.172 ($P < 0.1$) than those who have been accessed with training. The Wald statistics (6.014) also showed a highly significant association between access to solar training and SET adoption. This result contrasted with the previous study by Keriri, (2013), who found that as households got training about the use of the solar energy technology, the probability of their adoption increase. This means training removes their previous doubt about the technology and ensures their ability to decide whether to accept or reject it in a reasonable manner. This finding is contrary with Keriri, (2013); and Mustefa, (2021), who found that there was a positive relationship between solar energy technology adoption and either formal or informal training delivered. Therefore, the provision of training to rural households increases their awareness level and their inclination to adopt the solar energy technology at the household level. This result is a negative relationship between the adoption of a solar energy technology and training access.

Own cell phone: The own cell phone of the household is found to be one important factor in households' decision to adopt solar energy technology. The study showed that the own cell phone of households has a positive and statistically significant ($P < 0.05$) effect on solar energy technology adoption (see Table 12). The odd ratio of the binary logistic regression model showed that the adoption of respondents who have own cell phone of household about the solar energy technology is higher by a factor a factor of 2.836

($P < 0.1$) as compared to households who had not own cell phone of household about solar. The Walder statistics (7.518) also indicated the strong association between own cell phone and solar energy technology adoption. The variable found to have a positive influence on the adoption of modern and clean energy technologies (Abera, 2019). Thus, in this study mobile phone access was expected to have a positive effect on the adoption of solar energy technology.

Table 4.8. Results of logistic regression model on determinants of households ‘adoption of SET

Variables	Coef.	S.E.	Wald	P-value	Odd ratio
Income	0.946	0.257	13.538	0.00***	2.576
Credit access	-1.315	0.32	16.872	0.00***	0.268
Age of HH	-2.373	0.556	18.23	0.00***	0.093
Land size	0.216	0.678	0.101	0.75	1.241
Sex of HH	0.352	0.408	0.744	0.388	1.422
Education level	3.293	0.317	107.82	0.00***	26.923
Prior info	-1.553	0.584	7.076	0.008***	0.212
Own cell phone	1.042	0.38	7.518	0.006***	2.836
Media access	0.158	0.515	0.094	0.759	1.171
Training access	-1.761	0.718	6.014	0.014**	0.172
Constant	2.785	1.034	7.264	0.007***	16.154
Hosmer-Lemshow test	0.257				
NagelkerkeR ²	0.811				
Cox & Snell R Square	0.557				
-2loglikelihood	120.87				
No. of observation	349				

Note: *, ** and *** show significance levels at 10%, 5% and 1%, respectively

Source: Own computation results based on survey data, 2024.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Based on the finding, the challenges and barriers facing solar energy technology in the context of Ziquala district were identified through reviewing policy documents, feasibility studies, energy sector reports, questionnaires, interviews with the KIs and FGD with experts of relevant educational background to the study. The survey and document review conducted in this paper identifies several key barriers affecting the adoption of solar energy in Ziquala district include policy & regulatory frameworks, institutional, technological, information & human resource and societal barriers. This implies that most of the barriers identified from various studies in the majority from developing countries are also barriers in Ziquala district. This paper used binary logistic regression to evaluate the effect of household demographic, economic, and institutional factors the results showed that variables such as income level, educational level, and own cell phone are statistically significant and have a positive effect on solar energy adoption. On the contrary, while variables such as age, sex of household, training and credit access are statistically significant but negatively affect solar energy adoption. The solar radiation levels in Tsitsqa having the highest average radiation across the year and good enough for solar energy generation with the highest potential while Lalibela and Amdework still receive decent levels of solar radiation, but they would benefit from improved SETs.

This paper has confirmed the huge potential of solar energy in Ziquala district. It has also confirmed that Ziquala district has enough solar radiation to solve its energy needs. With the many areas of utilization of solar PV cutting across the household, education, health, agriculture, and commercial, to mention just but a few, as well as the multi-faceted benefits derivable from exploitation and utilization of solar PV, there is no doubt that solar PV holds the key to bail Ziquala district out of her perennial energy crises. Policy measures could directly target innovation through the development of local skills and technical capacity. The results of these selected studies approved that the area possesses high potential for solar energy possession of solar energy resources which have a central role in its future economic growth with great environmental benefits by reducing biomass and fossil fuel consumption

in the country.

5.2. Recommendations

The finding of this study indicates that the major barriers of solar energy technology in Ziquala district are policy and regulatory framework and economic factors so, it is recommended that the Ethiopian energy sector, decision-makers, policymakers, and concerned parties in the energy sector including, MoWIE, EEA to focus on the most relevant barriers when planning for energy to ensure a successful development of solar energy in the area. Technological and efficiency innovations are expected to have important roles in future energy investment pathways. Based on the findings of the current study the following recommendations are suggested.

- Government should subsidize the cost of importation of solar energy technology to bring down the high cost in Ethiopia and make it affordable.
- More research into the techno-economies involving the initial and subsequent costs of solar plants and their power efficiencies should be encouraged.
- Private individuals and organizations should be encouraged by appropriate authorities to invest in solar technologies in the country.
- Government should create more awareness of the advantages derivable from solar energy technology.
- Funding for solar technology research and development initiatives in Ethiopia Universities, Polytechnics and Research Institutes to develop solar PVs with increased efficiency that will be adaptable to our environment is advocated as is obtainable in developing countries.
- At last, PV electricity is the most viable option for power supply in areas where grid electricity is not reachable due to difficult topography, poor infrastructure and the resultant inaccessibility. Private investors and NGOs need to be encouraged to participate in the process of expanding PV-based off grid power into rural areas.

REFERENCES

- Abdel-Hadi, Y. A. (2021). *Diffuse Solar Radiation Modeling*. Shineeks Publishers.
- Abera, F. (2019). Determinants of lighting energy transitions in rural Ethiopia: lessons from Mida Oromo and Wonisho Districts of Ethiopia. *Environmental Management and Sustainable Development*, 8(3), 13.
- Abotsi, A. K. (2016). Power outages and production efficiency of firms in Africa. *International Journal of Energy Economics and Policy*, 6(1), 98–104. <https://doi.org/10.2139/ssrn.2729838>. *Sustainability (Switzerland)*, 12(12), 1–26. <https://doi.org/10.3390/SU12124859>
- Adaramola, M. S. (2012). Estimating global solar radiation using common meteorological data in Akure, Nigeria. *Renewable Energy*, 47, 38–44.
- Adeyemi, & Akinwale, Y. O. (2019). Factors influencing willingness to adopt renewable energy technologies among micro and small enterprises in Lagos State Nigeria. *International Journal of Sustainable Energy Planning and Management*, 19, 69–82.
- Akinoğlu, B. G., & Ecevit, A. (1990). Construction of a quadratic model using modified Ångström coefficients to estimate global solar radiation. *Solar Energy*, 45(2), 85–92.
- Akinwale, Y. O., & Adepoju, A. O. (2019). Factors influencing willingness to adopt renewable energy technologies among micro and small enterprises in Lagos State. 19, 69–82.
- Anaba, S. A., & Olubusoye, O. E. (2021). Determinants of use of solar energy as an alternative means of energy by small and medium enterprises in Lagos State, Nigeria. *Discover Sustainability*, 2(1), 29.
- Angstrom, A. (1924). Solar and terrestrial radiation. Report to the international commission for solar research on actinometric investigations of solar and atmospheric radiation. *Quarterly Journal of the Royal Meteorological Society*, 50(210), 121–126.
- Ashebir, & Desta K. (2021). Ethiopia renewable energy potentials and current state. *Aims Energy*, 9(1).
- Ashenafi, Ayall Negash, W., & Teshome, M. (2023). The Status of Solar Energy Utilization and

- Development in Ethiopia. *American Journal of Applied Scientific Research*, 13(1000307). <https://doi.org/10.11648/j.ajasr.20230903.13>
- Asmare Mossie, & Dawit Diriba. (2021). Factors Influencing Household Adoption of Solar Home System in Baso Liben District, Amhara Regional State of Ethiopia.
- Asmelash, E., & Gorini, R. (2021). *International oil companies and the energy transition*, International Renewable Energy Agency, Abu Dhabi About IRENA The International Renewable Energy Agency (IRENA) serves as the principal platform for international co-operation, a centre of excellence, .
- Awogbemi, O., Oluwaleye, I. O., & Komolafe, C. A. (2015). A survey of solar energy utilization for sustainable development in Nigeria. *Journal of Multidisciplinary Engineering Science and Technology*.
- Bais, A. F., Lucas, R. M., Bornman, J. F., Williamson, C. E., Sulzberger, B., Austin, A. T., Wilson, S. R., Andrady, A. L., Bernhard, G., & McKenzie, R. L. (2018). Environmental effects of ozone depletion, UV radiation and interactions with climate change: UNEP Environmental Effects Assessment Panel, update 2017. *Photochemical & Photobiological Sciences*, 17(2), 127–179.
- Barzani, M. (2021). Adoption of solar energy technology in rural Ethiopia: The case of East Hararge Zone, Oromia Regional State, Ethiopia. Haramaya university.
- Bensch, G., Peters, J., & Sievert, M. (2017). The lighting transition in rural Africa—From kerosene to battery-powered LED and the emerging disposal problem. *Energy for Sustainable Development*, 39, 13–20.
- Betak, J., Caltik, M., Cebecauer, T., Chrkavy, D., Erdelyi, B., Rosina, K., Suri, M., & Suriova, N. (2020). Global Photovoltaic Power Potential by Country. *Energy Sector Management Assistance Program (ESMAP)*. (World Bank Group, Washington, DC).
- Bhutto, A. W., Bazmi, A. A., Karim, S., Abro, R., Mazari, S. A., & Nizamuddin, S. (2019). Promoting sustainability of use of biomass as energy resource: Pakistan's perspective. *Environmental Science and Pollution Research*, 26, 29606–29619.

- Bollinger, B., & Gillingham, K. (2012). Peer effects in the diffusion of solar photovoltaic panels. *Marketing Science*, 31(6), 900–912.
- Charles. (2018). *Policy Framework and Programme Design for Small Hydropower and Solar Energy Development in Africa Final Report*. Retrieved from <https://au.int/> (pp. 259–273). Springer.
- Christian. (2019). The Determinants of Households' Adoption of Solar Energy in Rural Ethiopia: The case study of Gurage Zone. Available at: <Http/Localhost: 80/Xmlui/Handle/123456789, 18658>.
- Chukwuebuka, Gebresamuel, G., Retta, A. N., Zenebe, A., & Haile, M. (2019). Advances in quantifying soil organic carbon under different land uses in Ethiopia: a review and synthesis. *Bulletin of the National Research Centre*, 43, 1–24.
- Conti, J., Holtberg, P., Diefenderfer, J., LaRose, A., Turnure, J. T., & Westfall, L. (2016). *International energy outlook 2016 with projections to 2040*. USDOE Energy Information Administration (EIA), Washington, DC (United States
- Datta, A., & Karakoti, I. (2010). Solar resource assessment using GIS & remote Sensing techniques. *Vol. 9560272741, No. M*, 1–20.
- Dawit. (2010). *hiopian Energy Systems- Potentials, Opportunities and Sustainable Utilization*.
- Dawit. (2012). Application of an almost ideal demand system (AIDS) to Ethiopian rural residential energy use: Panel data evidence. *Energy Policy*, 50, 528–539.
- Dawit, D. (2018). Determinants of household adoption of solar energy technology in rural Ethiopia. *Journal of Cleaner Production*.
- Dawit, D. (2020). Determinants of household use of energy-efficient and renewable energy technologies in rural Ethiopia. *Technology in Society*, 61, 101249.
- Dawit, O, E., & Bekele, G. (2021). Long-term evolution of energy and electricity demand forecasting: The case of Ethiopia. *Energy Strategy Reviews*, 36, 100671.
- De Groote, O., Pepermans, G., & Verboven, F. (2016). Heterogeneity in the adoption of photovoltaic

- systems in Flanders. *Energy Economics*, 59, 45–57.
- Dereje. (2004). *Preliminary survey of livestock production systems in Ziquala Woreda, Waghimira zone of Amhara regional state*. MS Thesis. Alemaya Univ., Ethiopia.
- Dereje. (2014). *Modeling and analysis of long-term energy scenarios for sustainable strategies of Ethiopia*.
- Développement, P. des N. unies pour le, Unies, N., & L'énergie, C. mondial de. (2000). *World energy assessment: energy and the challenge of sustainability*. United Nations development programme.
- Do, . (2020). *Underlying drivers and barriers for solar photovoltaics diffusion: The case of Vietnam*. *Energy Policy*, 144(April), 111561. <https://doi.org/10.1016/j.enpol.2020.111561>. 15(9), 1–10. <https://doi.org/10.3390/ijerph15091903>
- Dorothal, M. (2019). Ethiopia solar report. *Solarplaza International BV*.
- Duffie, J. A., & Beckman, W. A. (2013). *Solar engineering of thermal process*. A Wiley-Interscience Publication, Estados Unidos Da América, 2.
- Engidaw, Salau, A. O., & Godebo, A. J. (2021). Assessment of solar energy potential of east gojjam zone Ethiopia using angstrom-prescott model. *International Journal of Engineering Research in Africa*, 53, 171–179.
- Falayi, E. O., Rabi, A. B., & Teli, R. O. (2011). Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria. *Advances in Applied Science Research*, 2(4), 480–490.
- Fikremariam. (2014). *Assessment of Solar Energy Resources in Ethiopia*. May.
- Flavin, C., & Aeck, M. H. (2005). *Energy for development: the potential role of renewable energy in meeting the millennium development goals*. Prepared for the Renewable Energy Policy Network by the Worldwatch Institute.
- Gana, N. N., Rai, J. K., & Momoh, M. (2014). Estimation of global and diffuse solar radiation for Kebbi, North-Western, Nigeria. *International Journal of Scientific & Engineering Research*, 5(1), 1654–

1661.

- Gärtner, & Stamps, A. M. J. P. (2014). *Ethiopian power grid*. Retrieved from <http://repository.tue.nl/778636>. 25(1), 44–50. [https://doi.org/10.1659/0276-4741\(2005\)025\[0044:trocic\]2.0.co;2](https://doi.org/10.1659/0276-4741(2005)025[0044:trocic]2.0.co;2)
- Girma, M. (2016). Viability of Solar/Wind and hybrid water pumping system for Off-Grid rural areas in ethiopia. Addis Ababa University Doctorial Thesis.
- Girum, Besha, A. T., Mekonnen, Y. S., Benti, N. E., Gebreslase, G. A., & Tufa, R. A. (2021). Opportunities and challenges of renewable energy production in Ethiopia. *Sustainability*, 13(18), 10381.
- Gitone, I. (2014). *Determinants of adoption of renewable energy in Kenya*. University of Nairobi.
- Guest. (2019). *Structured vs. Unstructured Questions | Cvent Blog*. Retrieved July 5, 2021, from <https://www.cvent.com/en/blog/events/structured-vs-unstructured-questions>.
<https://doi.org/10.1016/j.jaridenv.2006.10.009>
- Hilawe, Beza Hailu, T. H., & Carter, S. (2017). A climate for solar power: Solutions for Ethiopia's energy poverty. *Climate and Developments Knowledge Network (CDKN)*.
- IEA. (2020). *Access to electricity – SDG7: Data and Projections – Analysis - IEA*. Retrieved August 2, 2021, from <https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity>. 9(11121), 377–382.
- Iqbal, M. (1980). Prediction of hourly diffuse solar radiation from measured hourly global radiation on a horizontal surface. *Solar Energy*, 24(5), 491–503.
- Irena, I. (2018). Renewable power generation costs in 2017. Report. *International Renewable Energy Agency, Abu Dhabi*.
- Irena, I. (2019). Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects. *Abu Dhabi*.
- Irfan. (2019). *Solar Energy Development in Pakistan: Barriers and Policy Recommendations*.

- Sustainability, 11(4), 1206. <https://doi.org/10.3390/su11041206>. 18.
- Jamil, M., Ahmad, F., & Jeon, Y. J. (2016). Renewable energy technologies adopted by the UAE: Prospects and challenges—A comprehensive overview. *Renewable and Sustainable Energy Reviews*, 55, 1181–1194.
- Jiang, Y. (2009). Correlation for diffuse radiation from global solar radiation and sunshine data at Beijing, China. *Journal of Energy Engineering*, 135(4), 107–111.
- Kalota, D., & Khan, M. F. (2022). Comparing Performance of Inverse Distance Weighting and Modified Shepard Interpolation Models with Different Sampling Arrangements: A Case Study. In *Re-envisioning Advances in Remote Sensing* (pp. 239–249). CRC Press.
- Kassa. (2019). *Current Status, Future Potential and Barriers for Renewable Energy Development in Ethiopia*. *Iranian (Iranica) Journal of Energy and Environment*, 10(4), 269–274.
- Kebede. (2014). *Diffusion of solar innovations in Ethiopia: Exploring systemic problems*. *International Journal of Technology Management and Sustainable Development*, 13(1), 53–72. https://doi.org/10.1386/tmsd.13.1.53_1. 5–8.
- Kebede. (2015). *Viability study of grid-connected solar PV system in Ethiopia*. *Sustainable Energy Technologies and Assessments*, 10, 63–70. <https://doi.org/10.1016/j.seta.2015.02.003>.
- Keriri, I. K. (2013). Factors influencing adoption of Solar technology in Lakipia North constituency, Kenya. University of Nairobi.
- Kiflom, Mondal, M. A. H., Ringler, C., & Gebremeskel, A. G. (2019). Optimization and cost-benefit assessment of hybrid power systems for off-grid rural electrification in Ethiopia. *Energy*, 177, 234–246.
- Kwan, C. L. (2012). Influence of local environmental, social, economic and political variables on the spatial distribution of residential solar PV arrays across the United States. *Energy Policy*, 47, 332–344.
- Legesse & Chawla. (2016). Determinants of adoption of renewable energy sources towards reducing

- deforestation in ambo district, West shoa, oromia regional state, Ethiopia. *Journal of Energy Technologies and Policy*, 6(11), 23–41.
- Legesse, A. N. (2011). *Electric power demand, and the growth and transformation plan of Ethiopia*. ESEE.
- Lewis, N. S., & Nocera, D. G. (2006). Powering the planet: Chemical challenges in solar energy utilization. *Proceedings of the National Academy of Sciences*, 103(43), 15729–15735.
- Luthra. (2015). *Barriers to renewable/sustainable energy technologies adoption: Indian perspective*. *Renewable and Sustainable Energy Reviews*, 41, 762–776. <https://doi.org/10.1016/j.rser.2014.08.077>. 8(1), 0–15. <https://doi.org/10.1080/27658511.2022.2093058>
- Maddala, G. S. (2012). *Introduction to Econometrics. Second Edition. Macmillan Publishing Company, New York*.
- Mbachu, C. I., & Bizien, Q. (2017). *Adoption of innovation : A qualitative research about employees' adoption of information technological tool (ERP) within an organization*.
- Melessaw, Hankins, M., Saini, A., & Kirai, P. (2009). Ethiopia's Solar Energy Market. *Target Market Analysis, Deutsche Gesellschaft*.
- Mills, B. F., & Schleich, J. (2008). *Why don't households see the light?*
- Ministry of Water and Energy. (2012). *Scaling - Up Renewable Energy Program Ethiopia Investment Plan. Ministry of Water and Energy, Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia. (January), 81. Retrieved from www.h4sd.info landscape. 10(9), 1–30. https://doi.org/10.3390/land10090994*
- Mirzabaev, A., Guta, D., Goedecke, J., Gaur, V., Börner, J., Virchow, D., Denich, M., & von Braun, J. (2018). Bioenergy, food security and poverty reduction: trade-offs and synergies along the water–energy–food security nexus. In *Sustainability in the Water Energy Food Nexus* (pp. 60–78). Routledge.
- Mishra, K. (2018). *You are Approved! Insured Loans Improve Credit Access and Technology Adoption of Ghanaian Farmers*.

- Nadir Ahmed Elagib, N. A. E., & Mansell, M. G. (2000). *New approaches for estimating global solar radiation across Sudan*.
- Naomi, N. (2014). *Factors affecting the adoption of solar power for domestic usage in Kajiado country kenya. Masters tesis. Available at: <http://erepository.uonbi.ac.ke/bitstream/handle/11295/74308>. University of Nairobi*.
- Natei, Aneseyee, A. B., Abebe, A., Amente, C., & Mekonnen, Y. S. (2022). Estimation of global solar radiation using sunshine-based models in Ethiopia. *Cogent Engineering*, 9(1), 2114200.
- Newell, R., Raimi, D., & Aldana, G. (2019). Global energy outlook 2019: the next generation of energy. *Resources for the Future*, 1(8).
- Nikas, . (2020). *Barriers to and consequences of a solar-based energy transition in Greece. Environmental Innovation and Societal Transitions*, 35(December 2018), 383–399.
<https://doi.org/10.1016/j.eist.2018.12.004>. 105(4), 635–647.
<https://doi.org/10.1016/j.agee.2004.08.002>
- Ohunakin, . et al. (2014). *Solar energy applications and development in Nigeria: Drivers and barriers. Renewable and Sustainable Energy Reviews*, 32, 294– 301. <https://doi.org/10.1016/j.rser.2014.01.014>. United Nations development programme.
- Panos, E., Densing, M., & Volkart, K. (2016). Access to electricity in the World Energy Council’s global energy scenarios: An outlook for developing regions until 2030. *Energy Strategy Reviews*, 9, 28–49.
- Park, H.-A. (2013). An introduction to logistic regression: from basic concepts to interpretation with particular attention to nursing domain. *Journal of Korean Academy of Nursing*, 43(2), 154–164.
- Patrick. (2007). Reconsidering public attitudes and public acceptance of renewable energy technologies: a critical review. *Beyond Nimbyism: A Multidisciplinary Investigation of Public Engagement with Renewable Energy Technologies*, 15.
- Rahut, D. B., Mottaleb, K. A., Ali, A., & Aryal, J. (2018). The use and determinants of solar energy by Sub-Saharan African households. *International Journal of Sustainable Energy*, 37(8), 718–735.

- Rani, S., & Sud, D. (2015). Role of enhanced solar radiation for degradation of triazophos pesticide in soil matrix. *Solar Energy*, 120, 494–504.
- Samuel, & Bekele, G. (2014). Resource assessment and optimization study of efficient type hybrid power system for electrification of rural district in Ethiopia. *International Journal of Energy and Power Engineering*, 3(6), 331–340.
- Shahsavaria, A., Karimia, A., Akbarib, M., & Noughania, M. A. (n.d.). *Journal of Renewable Energy and Environment*.
- Smith, M. G., & Urpelainen, J. (2014). Early Adopters of Solar Panels in Developing Countries: Evidence from Tanzania. *Review of Policy Research*, 31(1), 17–37.
- Solomon, N. (2011). A Technical Study on Assessment of Resource Potential and Technological Options of Solar Energy and Photovoltaic Systems for Amhara Region, Ethiopia. June 2011.
- Stein, & Mesfin. (2020). Farm size and gender distribution of land: Evidence from Ethiopian land registry data. *World Development*, 130, 104926.
- Šúri, M., Huld, T., Dunlop, E. D., & Hofierka, J. (2007). Solar resource modelling for energy applications. In *Digital Terrain Modelling: Development and Applications in a Policy Support Environment* (pp. 259–273). Springer.
- Szabo, S., Bódis, K., Huld, T., & Moner-Girona, M. (2011). Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters*, 6(3), 34002.
- Tanko, F. (2023). Challenges and Outlook for Solar Energy Development in Africa. Available at SSRN 4474904.
- Tegenu, A. (2019a). Analysis of solar PV energy systems for rural villages of Nekemte area, Oromia Region, Ethiopia. *International Journal of Mental Health Promotion*, 26(8), 611–622. <https://doi.org/10.32604/ijmhp.2024.052730>
- Tegenu, A. (2019b). Estimation of global solar radiation on horizontal surface from sun shine hours and

- temperature at Kombolcha, Amhara Region, Ethiopia. *Journal of Energy, Environmental & Chemical Engineering*, 4(3), 39.
- Tegenu, Ashenafi, Natei Ermias, & Ashenafi Abebe. (2022). A comparative evaluation of artificial neural network and sunshine based models in prediction of daily global solar radiation of Lalibela, Ethiopia. *Cogent Engineering*, 9(1), 1996871.
- UNIDO. (2010). *Study on Local Manufacturing of Renewable Energy Technology Components in East Africa*. 6(4), 1–14. <https://doi.org/10.1002/agg2.20420>
- Ushizimpumu, C. (2016). *Development of Renewable Energy System Planning for Rural Electrification, Case Study Rwanda*.
- Van de Graaf, T. (2014). International energy agency. In *Handbook of governance and security* (pp. 489–503). Edward Elgar Publishing.
- Wang. (2021). *Exploring opportunities and challenges of solar pv power under carbon peak scenario in china: A pest analysis*. *Energies*, 14(11), 1–28. <https://doi.org/10.3390/en14113061>.
<https://doi.org/10.1186/s40068-021-00224-6>
- World Bank. (2021). *Firms experiencing electrical outages (% of firms) | Sub-Saharan Africa Data*. Retrieved July 30, 2021, from <https://data.worldbank.org/indicator/IC.ELC.OUTG.ZS>. 9(1), 2114200.
- World Bank Group. (2015). *Enhancing Urban Resilience*. Retrieved from www.worldbank.org/urban. 9(1), 1–29. <https://doi.org/10.1186/s40068-020-00194-1>
- WMO. (2008). *Guide to Meteorological Instruments and Methods of Observation*. Tech. rep., The GEOS-5 Data Assimilation System-Documentation of Versions 5
- Yamane, T. (1967). *Elementary sampling theory*.
- Yibeltal, T., & Adaramola, M. S. (2021). Socio-economic and environmental impacts of rural electrification with Solar Photovoltaic systems: Evidence from southern Ethiopia. *Energy for Sustainable Development*, 60, 52–66.
- Zhang, & C. (2012). *The diffusion of solar energy use in HK: What are the barriers?* *Energy Policy*, 41,

241–249. <https://doi.org/10.1016/j.enpol.2011.10.043>. 46(4), 385–395.

<https://doi.org/10.1016/j.clay.2009.10.001>

ZWWEO. (2023). ZWWEO (*Ziquala Woreda water and energy office report*).(2023). *Annual report, Ziquala*.

APPENDIX

Appendix Table 1: Calculated monthly average daily global solar radiation and input parameters of the three stations from (2009 – 2018).

Station	Month	Sunshine hour (S)	So avg	Hcal kWhm ⁻² d ⁻¹	Ho kWhm ⁻² d ⁻¹	Hcal/Ho	S/So
Tsitsqa	Jan	9.38	11.30	5.59	8.50	0.67	0.83
	Feb	9.39	11.60	6.12	9.30	0.65	0.81
	Mar	9.37	11.90	6.72	10.32	0.64	0.79
	Apr	9.21	12.30	7.07	11.00	0.64	0.75
	May	8.80	12.60	7.02	11.20	0.62	0.70
	Jun	7.18	12.77	6.40	11.22	0.57	0.56
	Jul	5.99	12.70	5.80	11.20	0.51	0.47
	Aug	5.86	12.40	5.76	11.10	0.52	0.47
	Sep	7.83	12.10	6.47	10.60	0.61	0.65
	Oct	8.99	11.70	6.28	9.78	0.65	0.77
	Nov	9.28	11.40	5.71	8.70	0.67	0.82
	Dec	9.27	11.20	5.37	8.20	0.67	0.82
Lalibela	Jan	9.39	11.38	5.63	8.62	0.65	0.82
	Feb	9.26	11.62	6.09	9.45	0.65	0.80
	Mar	8.15	8.15	6.33	10.38	0.61	0.68
	Apr	8.13	8.13	6.62	10.98	0.61	0.66
	May	7.38	7.38	6.34	11.13	0.57	0.59
	Jun	5.50	5.50	5.49	11.11	0.49	0.43
	Jul	3.82	3.82	4.51	11.13	0.40	0.30
	Aug	4.29	4.29	4.84	11.08	0.44	0.35
	Sep	5.89	5.89	5.53	10.65	0.52	0.49
	Oct	7.78	7.78	5.88	9.83	0.60	0.66
	Nov	8.63	8.63	5.52	8.82	0.63	0.76
	Dec	9.44	9.44	5.45	8.34	0.65	0.84
Amdewo rk	Jan	9.61	11.4	5.65	8.67	0.67	0.85
	Feb	9.60	11.6	6.07	9.31	0.65	0.83
	Mar	8.71	11.9	6.34	10.14	0.61	0.73
	Apr	8.47	12.3	6.50	10.60	0.59	0.69
	May	8.11	12.6	6.37	10.6	0.60	0.64
	Jun	6.75	12.71	5.80	10.49	0.57	0.53
	Jul	5.07	12.67	4.92	10.49	0.47	0.40
	Aug	4.10	12.4	4.48	10.50	0.43	0.33
	Sep	7.00	12.08	5.86	10.21	0.59	0.58
	Oct	9.02	11.70	6.01	9.51	0.60	0.77
	Nov	9.09	11.42	5.58	8.72	0.64	0.80
	Dec	9.64	11.3	5.41	8.3	0.68	0.86

Appendix Table 2: The mean sunrise hour angle (Ws), solar declination angle (δ) and regression constant for the three stations from (2009-2018)

Station	Month	Ws (deg)	δ (deg)	a	b
Tsitsqa	Jan	85.0	-20.9	0.39	0.32
	Feb	86.90	-13.36	0.39	0.35
	Mar	89.52	-2.32	0.38	0.38
	Apr	92.32	9.56	0.36	0.39
	May	94.62	18.84	0.33	0.42
	Jun	95.7	23.1	0.30	0.52
	Jul	95.2	21.06	0.27	0.60
	Aug	93.18	13.24	0.28	0.58
	Sep	90.48	1.92	0.32	0.47
	Oct	87.88	-9.06	0.38	0.38
	Nov	85.4	-19.14	0.39	0.36
	Dec	84.38	-23.1	0.39	0.34
<u>Lalibela</u>	Jan	85.4	-20.90	0.39	0.34
	Feb	87.2	-13.36	0.38	0.36
	Mar	89.52	-2.31	0.34	0.43
	Apr	92.12	9.57	0.33	0.45
	May	94.22	18.84	0.31	0.50
	Jun	95.3	23.10	0.30	0.64
	Jul	94.78	21.06	0.22	0.70
	Aug	92.9	13.23	0.23	0.67
	Sep	90.48	1.91	0.28	0.57
	Oct	88.084	-9.06	0.33	0.45
	Nov	85.8	-19.14	0.36	0.38

	Dec	84.8	-23.1	0.39	0.33
<u>Amdework</u>	Jan	85.44	-19.99	0.4	0.31
	Feb	87.06	-13.43	0.40	0.33
	Mar	89.51	-2.32	0.36	0.39
	Apr	92.13	9.56	0.35	0.43
	May	94.33	18.84	0.30	0.47
	Jun	95.40	23.10	0.30	0.54
	Jul	94.90	21.06	0.26	0.62
	Aug	92.99	13.24	0.23	0.67
	Sep	90.47	1.92	0.30	0.51
	Oct	88.08	-9.06	0.40	0.38
	Nov	85.72	-18.98	0.38	0.35
	Dec	84.70	-23.10	0.4	0.31

Appendix Table 3: Calculated global, direct and diffuse solar radiation on horizontal surface for the three stations from (2009-2018)

Station		Jan	Feb	May	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Tsitsqa	H	5.59	6.12	6.72	7.07	7.02	6.4	5.8	5.76	6.47	6.28	5.71	5.37	6.18
	Hd	1.33	1.32	1.3	1.39	1.24	1.1	1.02	1.02	1.19	1.28	1.32	1.32	1.23
	Hb	4.26	4.8	5.42	5.68	5.78	5.3	4.78	4.74	5.28	5	4.39	4.05	4.96
Lalibela	H	5.63	6.09	6.33	6.62	6.34	5.49	4.51	4.84	5.53	5.88	5.52	5.45	5.69
	Hd	1.31	1.29	1.21	1.17	1.12	0.98	0.89	0.92	1.01	1.28	1.25	1.32	1.37
	Hb	4.32	4.8	5.12	5.45	5.22	4.51	3.62	3.92	4.53	4.6	4.27	4.13	4.32
Amdew ork	H	5.65	6.07	6.34	6.5	6.37	5.8	4.92	4.48	5.86	6.01	5.58	5.41	5.75
	Hd	1.35	1.31	1.24	1.20	1.17	1.06	0.96	0.89	1.10	1.21	1.28	1.31	1.18
	Hb	4.30	4.76	5.10	5.3	5.2	4.74	3.96	3.59	4.76	4.8	4.30	4.10	4.57

Appendix Table 4: Angstrom equation for the study sites from (2009-2018)

Site	A	B	Angestrom equations
Tsitsqa	0.35	0.42	$H_{cal}/H_o = 0.35 + 0.42 (S/S_o)$
Lalibela	0.32	0.48	$H_{cal}/H_o = 0.32 + 0.48 (S/S_o)$
Amdework	0.34	0.44	$H_{cal}/H_o = 0.34 + 0.44 (S/S_o)$
Average	0.34	0.45	$H_{cal}/H_o = 0.34 + 0.45 (S/S_o)$

Appendix Table 5: Determination of number of day in all stations

Month	n for ith number of days of the month
January	I
February	31+i
March	59+i
April	89+i
May	120+i
June	150+i
July	181+i
August	212+i
September	242+i

October	273+i
November	303+i
December	334+i

Appendix Table 6: Household survey questionnaire

I am student at Bahir Dar University Zenzelima Campus College of Agriculture and Environmental Science. As a part of my study program, I am undertaking a study to Assessing solar energy potential and factors affecting adoption of solar energy technology in Ziquala district.

Dear Respondents:

The main purpose of this interview questionnaire is to acquire information relevant for a research entitled“Assessing solar energy potential and factors affecting adoption of solar energy technology in Ziquala district.” The research outcome is expected to be helpful for the improvement of solar energy dissemination program and other energy and environment related interventions. Therefore, your genuine answer to the interview questionnaire is a necessary condition for the reliability of this research outputs. The information is meant only for academic purpose. The responses you give will not have a negative impact on anybody. I honestly assure you that, your personal information will be kept confidentially. Hence, just feel free to provide the correct answer. I am very much grateful to the favorable contribution of your time and energy to the success of this study.

N.B:

✓ for some tabular questions, please put tick mark () where needed.

✓ for questions that request ranking, please write the ranks1, 2, 3, in the boxes only for choices applicable to your case by giving value 1 for the best choice, 2 for the 2nd best, etc.

Name of interviewer: _____ Name of respondent_____Kebele _____ Date: _____

Section one: Socio-economic and demographic characteristics of households

1) Gender

- a) Male b) Female

2) Age

- a) 18-29 year b) 30-39 year c) 40-49 year d) 50-59 year e) 60 & above

3) Marital status

- a) single b) married c) divorced d) Widow

4) What is your Educational level of household head?

- a) Illiterate b) basic education c/ primary education (1-8) d/ secondary education (9_12)
e/ TVET and above

5) Average annual income in birr (ETB)

- a) 10,000 b) 10,000-30,000 c) 30,000 -50,000 d) 50,000-80,000 e) above 80,0000

Section two: Households' awareness and attitude on solar energy technology

6) What is your level of awareness of availability of solar technology service providers in Ziquala districts?

- a) Very aware b) Aware c) Not sure d) Unaware

7) Have you ever received any formal or informal training on solar energy systems?

- a) Yes b) No

8) If your answer for Q7 is yes, who initiated the idea about solar?

9) What was the usefulness level of the training you attended?

- a) Very useful b) Useful c) Not sure d) Not useful

10) Do you have awareness about solar energy technology?

- a) Yes b) No

11). If your answer for Q10 is yes, who initiated the idea about solar?

- a) Energy experts of the district b) Neighbors/relatives/friends c) Radio
d) Television e) NGOs f) solar researcher g) other

12). Households attitude towards solar energy technology

- a) Yes b) No

Section three: Utilization and Adoption of Solar

13) What energy source do you use for lighting?

- a) Electricity b) Paraffin c) Gas d) Firewood e) Dry cells f) Solar

14) Do you have use solar energy?

- a) Yes b) No

15) If your answer in Q14 is No what are the major reasons for not having solar?

- a) Higher installation cost b) Lack of awareness about the benefits of solar energy technology
c) high occurrence of drought

16) Do you have access local material for solar energy construction?

- a) Yes b) No

Section four: Promotion of solar energy technology

17) In your view how can solar energy potential and utilizations are promoted in Ziquala district?

18) Do you have adoption of solar energy technology?

- a) Adopter b) Non-adopter

Section five: For solar users

19) What was the major reason for using solar energy?

- a) High cost of other energy sources b) Government subsidy for the plant
- c) Broken or leaking pipes d) Shortage of cow dung e) No gas

20) Do you have credit accessibility?

- a) Yes b) No

Section six: Observation Schedule

1) Is its construction status

- a) Complete b) Incomplete

2) Presence of cattle: a) Present b) Absent

Section seven: Focus Group discussion Guide

1) What are the major energy sources in your area?

2) Is there energy problem in your area? If yes to what extent

3) Do you see a need for alternative energy sources? If yes which alternatives do you think are appropriate to your area?

4) what are the factors that affect adoption of solar energy technology in the study area?

Section eight: Checklist for Key Informant Interview

1. Which are most commonly used for domestic energy consumption in your locality? Why?

2. What is your view on the current status of fuel wood sources? Why?

3. Is charcoal production common in your locality?

4. When was dissemination of solar energy technology started in the kebele?

5. What are the problems that have been faced to on dissemination solar?

THANK YOU!!