Addis Ababa University
Addis Ababa Institute of Technology
Center for Renewable Energy

Techno Economic Feasibility Analysis of Mini-Grid Using Hybrid Renewable Energy System for Off-grid Community: a case of Shima Kebele North Shoa Ethiopia

A Thesis submitted to the school of Graduate studies at Addis Ababa Institute of Technology Center for Renewable Energy in partial fulfillment of the requirement for the degree of Master of Science in Renewable Energy Technology

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DECLARATION

I hear by declaring that this MSc thesis, titled **"*Techno-economic feasibility analysis of mini-grid using hybrid renewable energy system for off-grid community: a case of Shima kebele North Shoa Ethiopia*"** was completed independently by me **Mekdem Tesfamariam** under the supervision of **Dr. Fitsum Salehu** (Assistant Professor). This MSc thesis was not submitted for the purpose of receiving any other degree or professional qualification.

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This is to certify that the thesis prepared by **Mekdem Tesfamariam** entitled "**Techno economic feasibility analysis of Mini-Grid using hybrid renewable energy system for off-grid community: a case of Shima kebele North Shoa Ethiopia".** It submitted in partial fulfillment of the requirements for the degree of Master of Science in Renewable Energy Technology (Center for Renewable Energy). Complies with the regulations of the University, and meets the accepted standards with respect to originality, and quality.

By:
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ABSTRACT

Lack of clean and sustainable energy access is the biggest challenge for developing countries like Ethiopia. Many Ethiopian rural areas are not suitable for grid connections due to their geographical location and low number of residents. Rural communities utilize kerosene and biomass resources to meet their household energy demand, and the farmers employ large-scale irrigation schemes using diesel pumps. This causes a reduction in their profit gain and increases their expenses, including the cost of diesel pump maintenance and diesel oil transport. This study aims to assess the techno-economic feasibility of mini-grid solar energy for Shima Kebele, North Shoa, Ethiopia, which can provide reliable energy to the village. The energy demand of the study area is determined by conducting a questionnaire, a site visit, and using CROPWAT 8.0 software to determine the water requirement for irrigation. Onion water requirement is 8.65 mm/day and Tomatoes water requirement is 11.04 mm/day, which is equivalent to 4,922.5 m^3/day required to irrigate 50 hectares. HOMER software is used to compute the techno-economics of various system configurations. The daily energy demand of the kebele is 1,568 kWh, where, around 67 % of the load is irrigation. The proposed optimal system consists of 343 kW of solar PV and a 60 kW generator. The proposed system NPC is USD 494,107 and the COE is USD 0.0885/kWh. The cost benefit analysis for irrigation was also done. The electricity saves around $36,000 per annum when compared to diesel. The system will improve the lives of rural communities in several ways. The result of the study can help encourage the different stakeholders to invest in mini-grids to tackle the socio-economic problems of the rural community, which will be a feasible and environmentally friendly solution.

Keywords:

Mini-grid solar PV, Clean Energy Acess, Irrigation, HOMER, CROPWAT, COE

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LIST OF ABBREVIATIONS AND ACRONYMS

CAPEX	Capital Expenditure
CC	Cycle Charging
COE	Cost of Energy
CWR	Crop water requirement
DG	Diesel Generator
GHG	Greenhouse Gases
GPS	Global Positioning System
HES	Hybrid energy system
IEA	International Energy Agency
IR	Irrigation requirement
LF	Load Following
M	Million
MHP	Hydropower
NASA	National Aeronautics and Space Administration
NEP	National Electrification plan
NOCT	Nominal Operating Cell Temperature
NPC	Net present cost
OPEX	Operating Expenditure
RE	Renewable Energy
SOC	State of charge
STC	Standard Test Conditions
USD	United States Dollar

Nomenclature

A	Ampere
Ah	Ampere Hour
C_{Pmax}	power coefficient/Betz's coefficient
es	Saturation vapour pressure
ETc	Crop Evapotranspiration
Eto	Reference Evapotranspiration
G	Soil heat flux density
GT	Solar radiation under normal condition
I_{mpp}	Current at maximum power point
I_{sc}	Current at short circuit
Kc	Crop coefficient
km	Kilo meter
kPa	Kilo pascal
kVA	Kilo Volt Ampere
kW	Kilo Watt
kWh	Kilo watt hour
kWp	Kilo watt peak
m/sec	Meter per second
m^2	Meter square
m^3	Meter cubic
MJ	Mega Joule
mm	Milli meter
MW	Mega watt
^oC	Degree cent grade
P_{atm}	Atmospheric air pressure

P_{max}	Maximum power
Rn	Net radiation at the crop surface
RPM	Revolution per minutes
T	Temperature
V	volts
v	Wind speed
V_{mpp}	Voltage at maximum power point
V_{oc}	Voltage at open circuit
Z	Height above ground
α	Solar absorbance
γ	psychrometric constant (kPa/^{o}C)
ρ	density
τ	Solar transmittance
$	United states dollar
α_P	The temperature coefficient of the power
$\eta_{mp,STC}$	Maximum power point efficiency under the test condition
Δ	slope vapour pressure curve (kPa/^{o}C),

1. INTRODUCTION

1.1. Background

One of the vital elements for the development process is energy without any question. Without energy, it is very challenging to sustain development. Energy is a key aspect of socio-economic growth that affects nearly every scope of human life, and an important condition for human growth [1]. The prolonged delivery and use of energy facilities strongly related to economic growth reveals how significant energy is a vital factor in socio-economic growth. The modern lifestyle which includes well-being, education, and health cannot be preserved without adequate energy [2].

According to [3] the Electricity access in Ethiopia has reached 48% in 2019. The country's 80% population lives in the rural part of the country, where electrification is presently focused in urban areas [4]. Until 2019, rural households that are grid-connected are only 34% [5]. Ethiopia has issued National Electrification Program 2.0 (NEP 2.0) in 2019 that aimed to present the action plan for attaining universal electricity access throughout the country by 2025[6]. NEP 2.0 outlines the country's ambition to achieve 100% electricity access by the year 2025. This 100% electricity access was planned to be achieved through 65% by grid connection and 35% by the off-grid connection[6]. The off-grid connection is achieved by using mini-grid technologies and stand-alone solar systems.

According to the IEA estimations, globally 30% people without access to electricity would best be served by national grid extension, 17.5% people without access to electricity would best be served by stand-alone energy systems, and 52.5% people without access to electricity would be served by mini-grids [7].

Ethiopia has huge potential for mini-grid development. Sixteen percent of its population i.e. around 16 million people would be best served with mini-grids, which create the market size of USD 513-639 million [8]. The main developer of mini-grid in Ethiopia is Ethiopia Electric Utility (EEU), which operates diesel generator and micro hydropower plants. In 2018, EEU launched the installation of pilot solar mini-grids with battery backup systems in 12 various villages with the help of World Bank with capacity between 75kW to 550kW. An additional 25 sites are on bid process. If this pilot phase is successful, the project will expand to 250 villages as Independent Power Producers (IPPs) [9].

Lack of clean and sustainable energy access is the biggest challenge for developing countries like Ethiopia. Many of Ethiopia's rural areas are not suitable for grid connections due to their geographical location. Shima village is an off-grid area located 70km from Debre Birhan. The community uses biomass resources traditionally to cover their household's energy demand and some farmers utilize diesel pumps for their irrigation water needs. Although expensive and inconsistent diesel costs cause lower profits for farmers, the need for long-distance travel to obtain the fuel also affects working hours on the farm. Environmental pollution created by emissions from the pumps, and frequent breakage of the pumps is also a major challenge in the community. Exposure to indoor air pollution is due to the traditional usage of biomass, and women and children spend lots of their time collecting fuel wood in the community. The service quality of governmental institutions drops due to a lack of electricity, such as kebele administrative offices, health centers and schools. This study will try to address the suitable energy substitution that can meet the community energy needs for households, irrigation, and commercial and institutional energy needs through assessing the energy demand, sizing the mini-grid and conducting techno-economic analysis using HOMER software.

1.2. Problem Statement

Ethiopia has a huge potential for renewable energy resources (hydro, wind, solar, geothermal, and biomass). However, the majority of the population lives in rural areas where there is a lack of access to clean, reliable, and affordable energy sources, and they largely rely on traditional biomass such as wood, animal dung, and agricultural residues. The Ethiopian government plans and works to provide clean and affordable energy, but energy demand is increasing and project completion rates are very low. This causes energy shortages in urban areas and increases reliance on traditional biomass in rural areas. Ethiopia has a wealth of energy resources, including hydro, wind, solar, geothermal, biomass, coal, and natural gas but it hasn't been able to develop, transform, or use these resources to their full potential for economic growth [4].

Shima Kebele is a rural community situated in the northern part of Ethiopia and experiences problems related to access to electricity. It is not yet practicable to extend the grid in this village due to its geographic unsuitability and distance from the grid. The community utilizes kerosene and biomass resources to meet their household energy demand and the farmers employ large-scale irrigation schemes using diesel pumps. This causes a reduction in their profit gain and increases their expenses, such as the cost of diesel pump maintenance and diesel oil transport.

1.3. Objective

1.3.1. General Objective

- To assess the techno-economic feasibility of hybrid mini-grid which consists solar PV, wind, diesel generator and battery storage system for Shima Kebele, North Shoa, Ethiopia.

1.3.2. Specific Objective

- To assess the electrical load of the village, which includes households, local businesses (shops, mills, etc.), governmental institutions, telecommunication infrastructure and irrigation.
- To design and optimize the power supply using the hybrid mini-grid which consists solar PV, wind, diesel generator and battery storage system.
- To evaluate the HOMER optimization with various key economic indicators (i.e., net present cost, cost of energy).
- To conduct a sensitivity analysis.

1.4. Significance of the study

Energy is a critical requirement to improve the economic development of a country. Ethiopia has abundant renewable energy resources that can meet the country's electrification ambitions, but the community still suffers from a lack of access to electricity supply. Recently, the Ethiopian government has given great attention to providing electricity for the rural areas of the country through the implementation of solar mini-grids. This research study will have the following significances:

- It will be taken as a base input for further studies that involve irrigation at the sites.

- This study will give an answer to the community by supplying its power demand through possible hybrid mini-grid solutions. This will help in informed decision to invest in mini-grids for off-grid communities.

1.5. Scope of the study

The research encompasses load determination and techno-economic feasibility analysis of hybrid mini-grid system which consists solar PV, wind, diesel generator and battery storage system. This will provide electricity for households, business center, governmental institutions and irrigation of Shima kebele. In order to meet the objectives, important data will be collected and analyzed to design the most suitable system configuration.

1.6. Organization of the study

This study encompasses six major chapters. The first chapter includes the background of the study, problem statements, objectives, significance and scope of the study. The second chapter incorporates the literature review. The third chapter covers the scientific methods and materials used in the study. The fourth chapter presents the relevant input and data used for HOMER simulation and optimization. The fifth chapter consists of the result and discussion, and the last chapter deals about the conclusion and recommendation.

2. LITERATURE REVIEW

2.1. Introduction to Mini-grid

Mini-grids symbolize a key choice to deliver electricity access to places that are not supplied by national grids [10]. A mini-grid is a system that produces electricity that is separate and different from the main national electricity grid [11]. Mini-grid is another option to the national electricity grid in that it characteristically contains one or more electricity sources, a distribution network, and a storage system that provides electricity to a certain number of customers [12]. Mini-grid systems can be classified into two types. The first type is stand-alone, which operates independently from the national grid, and the second type is grid-connected, which can supply the national grid with its excess energy [13], [14].

Mini-grids have appeared as a cost-effective game-changer for rapid and exceptional electrification mechanisms for off-grid applications [15]. Mini-grids can provide power for household appliances and local businesses [16]. With the right circumstances, mini-grids can match national grid electrification policies for supplying access to electricity to off-grid communities, which in turn can lead to modernized living standards and economic activities [15].

Electricity from a grid network is still the preferred method of electrification internationally due to economies of scale, which decrease power supply costs [11]. However, the cost of expanding the network to rural areas is very expensive and not economical. Mini-grids can be a good alternative to the national grid where areas are located far away from the main grid [7]. Current technological and operational efficiencies, combined with a general cost decrease, have made mini-grids an attractive option for electrifying rural areas. Mini-grids fill vital space among individual solutions, like household-level systems like solar home systems and the normal national grid [13]. Mini-grid sector economies of scale steadily start to have an effect, like the costs of batteries and photovoltaics decreasing over time, which leads to mini-grid costs lowering. In the meantime, the development of mobile payment platforms, information technology (IT), and better system reliability have made mini-grids more interesting investments for the private and public sectors [17].

2.1.1. Classification of Mini-grids

Currently, there are various approaches to the mini-grid sector. The approaches are mainly divided into two categories. The first categories are the technologies, and the second categories are the financial and institutional arrangements [18]. Various literatures mention technologies like solar, hydro and biomass, diesel, and hybrid are used to develop mini-grids in various parts of the world [13], [19], [20], [21]. When two or more technologies are combined for power generation and electricity distribution, the system is called a hybrid mini-grid. In hybrid mini-grids, one or more renewable energy technologies with diesel generators are usually used as a backup system. The benefit of a hybrid mini-grid grid is that it will provide reliable electricity to the community, both economically and environmentally [16]. According to the global mini-grids market report, of the 5,544 mini-grids investigated, around 50% are using solar power, 21% are hydro, 13% are solar hybrid, 11% are diesel, 3.2% are biomass and others [14].

2.1.2. Ownership of Mini-grid

There are four different ownerships of mini-grids based on financial and institutional arrangements. The first ownership is public. The public is responsible for the generation and distribution of power of the mini-grid. In this approach, the mini-grid relies on subsidies from the public, so customers pay lower tariffs. The second ownership model is the private model. In the private model, the private company is responsible for the generation and distribution of power of the mini-grid. Most of the time, private-owned mini-grids don’t rely on subsidies, higher revenue risk, higher tariffs, and high transaction costs. The third ownership is the hybrid model. In this model, either generation or distribution will be handled either public or private. The fourth model is community-based. The mini-grid management will be handled by a cooperative organized by the community. Community-based mini-grid face challenges due to a lack of managerial and technical knowledge in the community [14], [17], [22].

2.1.3. Class and Size of Mini-grid

According to the mini-grid directive issued by the Ethiopian Energy Authority (EEA) in December 2020, it classifies the mini-grid into three classes [23]. Table 2. 1 shows the classification of mini-grids according to the EEA mini-grid directive based on the size and class.

Table 2. 1. Class and Size of Mini-grid

Class	Capacity
Class I	Less or equal to 50kW
Class II	Greater than 50kW and Less or equal to 200kW
Class III	Greater than 200kW and Less or equal to 10MW

2.1.4. Challenge of Mini-grid

There is huge opportunity for mini-grid development, but it is challenging to build a viable financial structure [24]. According to [25], they have listed 10 factors that challenge the development of mini-grids in rural parts of the world:

- Limited verified business models
- Gaps in regulations and policies
- Lack of a continuous financing mechanism
- High investment costs and low-capacity factors
- Higher tariffs
- Inadequate financing, support and investment
- Technology failures
- Inefficient management and maintenance
- Absence of mechanisms to address complaints.
- Likely future national grid expansion is uncertain.

2.1.5. Generation of Mini-grids

The first mini-grids were installed in the early 20th century and had been widely used in the energy sector in developed countries [22], [26]. But mini-grids are emerging as scalable alternative technologies for electrification demand in off-grid areas [22]. Mini-grids are now entering their fourth generation. The first-generation mini-grids are powered by steam, diesel, or hydro. The second-generation mini-grids are hybrid renewable energy with steam, diesel, or hydro. The difference between the first and the second generation is that the second generation mini-grids use more than one energy source (i.e. hybrid) but the first generation uses only one source of energy. The third-generation mini-grids incorporate information technologies to enhance customer satisfaction, improve tariff collection efficiency, and enable remote monitoring. The fourth-generation mini-grids are fully automated third-generation mini-grids. The fourth-generation mini-grids add a value chain to rural areas [17], [26].

2.2. Literature Review of Similar works

The techno-economic viability of a hybrid RE system for long-term rural electrification in Benin for a selected village was examined by O.D.T. Odou et al. [10]. Optimization, modeling, and sensitivity analysis were carried out using HOMER software. The demand assessment was done for the three categories of household, community, and commercial loads. The demand assessment had three types of load variation for three seasons. Out of thirteen optimization outputs, the researchers have selected the best system by using the least NPC and COE. The selected system was a hybrid PV/diesel generator/battery system. The NPC and COE of the system were $555,492 and $0.207/kWh, respectively. This system guarantees a consistent supply of electricity, decreases the need for batteries by 70% when compared to PV/battery systems, and reduces CO_2 emissions by 97% when compared to a traditional DG. Furthermore, the study showed that the most cost-effective hybrid RE system largely depends on the potential energy sources accessible at a place and the distance of the power plant from the beneficiary. In conclusion, the researchers advised using this hybrid PV/DG/battery system instead of the already extensively used PV/battery system for future electrification projects in Benin.

Ahmad et al. [11]examined the potential for power generation using a biomass, photovoltaic, and wind hybrid system for the local residents in Pakistan. The research focused on the techno-economic feasibility of such a system. Both the residential and commercial sectors took into consideration the cost of energy based on peak load demand profiles. The levelized cost of energy was 0.05744 $/kWh.

W.M. Amutha and V. Rajini [12]studied the utilization of renewable energy sources to the fullest extent possible for electrification in rural communities in India. The researchers conducted resource assessments for the RE sources, i.e., solar, wind and hydro. The RE sources, DG and battery were also considered by the system as backups. The HOMER simulation's results indicated that both solar/wind/hydro/battery and solar/wind/battery systems didn't emit any carbon dioxide and had lower NPC and COE. The Solar/Wind/Hydro/Battery system had also comparatively more stable electricity output than the Solar/Wind/Battery. RE sources had a complementing effect on each other when one of RE sources had weak potential in a specific period of the year and the other complemented the deficit energy. The researchers concluded that adding the battery to the system not only meets load demand but also reduces carbon emissions and COE.

Getachew and Getnet [13] conducted research to seek electrification options for Dejen area in Ethiopia. The study area was difficult to make grid-based electrification. Resources assessment was conducted for various RE sources like solar, wind and hydro. The load assessment was estimated for the basic needs for households like lighting, TV, radio, water pumps and mills and for the community, clinics and primary schools were considered. In the research the feasibility of hydro/PV/wind was studied. The hybrid system's optimization and sensitivity analysis are conducted using HOMER software. The COE of the system was $0.16/kWh which higher that national tariff, but the researchers suggested the like this system would benefit the country by addressing issues like energy shortage, deforestation and change in the lifestyle of rural community.

Bhatt et.al [14] examined the techno-economic viability of an off-grid hydro/PV/biomass and biogas/DG/battery system in India for a rural community. The planned hybrid energy system (HES) is intended to provide access to energy in five off-grid settlements. The load profile for households, community and industrial loads were considered. The two-seasonality variation was also considered. RE resources assessment was conducted. Based on the resources various types of models simulated and sensitivity analysis was carried out by HOMER. Micro hydro/ SPV/ Biomass/Biogas/Diesel/Battery system were selected as the best configurations. It was chosen configuration based on the lowest COE, lowest NPC, highest renewable percentage, and lowest carbon dioxide emissions.

A. Chauhan & R.P.Saini [15] studied an integrated RE system for un-electrified villages in India. The data were collected for both demand and resource assessment. The demand assessment was collected for domestic, commercial, agriculture and community. Biogas consumption for cooking was determined. The demand varied for the summer and winter season. Resources assessment was conducted for micro hydro, solar radiation, and wind speed, availability of biomass and availability of cattle dung. Nine possible combinations of renewable energy sources had also been researched while taking into account economic, technical, and social factors. The system's most sensitive parameter had been identified using a sensitivity analysis, which has also been done. HOMER was used technically, economical and social. The MHP- Biomass-Biogas -

Wind-PV-Battery based configuration was determined to be the most suitable option among the various combinations for the study area because it provided the lowest LCOE of $ 0.092/ kWh and NPC of $ 825,408.

Kolhe et.al [16] had studied techno-economic sizing for rural electrification by using RE systems in Sri Lanka. Demand and RE resource assessment were done for the study area. From the resource assessment, the researchers concluded that the study area have good potential of wind and solar. In addition to the two RE resources, Diesel generator and battery were also considered for the system. HOMER software was used to conduct simulation and sensitivity analysis. In order to assess the option with the lowest energy cost, the total net present cost of configuration had been determined for the system's lifespan of 20 years. The wind-PV-battery-diesel generator was found to have the optimum hybrid configuration. This system was capable of supplying electricity at $0.34/kWh. The researchers suggested that after 10 years of operation of the system as off-grid, the system is capable of working grid connected. The researchers concluded that the system is economically viable whether it is used off-grid or in conjunction with the grid.

Das et.al [17] had examined the techno-economic viability of stand-alone hybrid power generation for a distant settlement in Bangladesh. By using the software tool HOMER, the suggested system combines a biogas generator, PV, wind turbines, diesel generators, and battery to meet the electricity demand requirements. The load assessment and RE resources assessment was carried out. The authors used biogas generators to meet the peak load of the community. The diesel generator would be used when the PV and biogas generator failed to meet the electricity demand. The HOMER simulation results recommended that the hybrid system lowest COE and lowest NPC was PV/Biogas/Battery/Diesel. The system had better COE compared to solar home system and diesel generator. The researchers suggested that a system like this will add customer's satisfaction with quality and reliable energy solution.

Bekele and Palm [18] conducted feasibility study of a solar-wind hybrid system for the selected village in Ethiopia, which is located far from the national grid. The study was conducted for 200 families based on the load assessment for the households, school, and health post. The electricity loads were categorized as primary and deferrable. From HOMER simulation, DG/Battery system had the lowest NPC with zero renewable utilization percentage. The researchers considered the system with renewable energy utilization percentage, which result higher NPC and LCOE. They suggested that continue rising of the diesel price, whereas the price of RE equipment was expected to fall down. So, they believed that it is realistic to endorse the option of renewable energy due to various reasons even though it didn't explain with cost in their study case.

Mamaghani et.al [19] studied the techno-economical viability of hybrid RE systems for three rural villages of Colombia. Load estimation and resources assessment were conducted. The load of households, schools and health centers were considered. To find the best energy- and money-efficient design for each location, several combinations of wind turbine, PV, and diesel generator were first modeled and optimized by using HOMER software. Based on various configurations of PV, DG, and wind turbine, seven design examples were suggested and evaluated. In order to undertake a thorough parametric analysis on the system configurations and choose the most practical from an economic standpoint, HOMER was used to create a dynamic model of the plant. The economic indicators chosen were the NPC, COE, and initial capital cost. In addition to these, the resulting annual CO2 emissions were also calculated as an environmental index. The result of the study showed that diesel-RE systems had low CO2 emissions when it compared to diesel only systems. For one site, the PV/DG/wind/Battery was selected as the most cost-effective option whereas for the remaining two sites PV/DG/battery systems were selected. The DG systems were the most practical among the above configurations if capital costs were the sole factor taken into account but need to consider the challenge of transporting fuel to these areas. The authors concluded that hybrid and entirely renewable systems appear to be the most preferred designs from an environmental standpoint, and they may also be economically advantageous in the long run. The initial capital cost the most challenge to deploy these technologies, the authors suggest that the government of the Colombia should support by implementing tax reduction and exemptions.

Hossain et al. [20] conducted research of techno-economical assessment for large resort located in Malaysia. The electricity source of the resort was a diesel generator which emits CO_2 to the environment. Load estimation and solar and wind resources assessment were conducted. HOMER software was used for the optimization of the hybrid RE system, which results in thirteen possible configurations. The PV/Wind/ DG/Battery was selected as the best configuration for power plant for the resort. The selected system had the lowest NPC, COE and CO2 emission compared to diesel only system.

Tessema & Bekele [21] studied techno economic viability of Wind/PV/DG/Battery for remote rural area in Ethiopia. The authors had conducted the resource and load assessment for the study area. The area benefits from abundant solar and wind resources that can be used to generate electricity and power the community. To perform optimal sizing and techno-economic analysis, HOMER software was used. From the HOMER optimization results, eleven possible configuration of system were obtained. From these results, Wind/PV/DG/Battery was selected due to its lowest NPC and COE. The wind turbine supplied 92% of the energy produced by the turbine. The researcher studied grid extension as another alternative, but the capital cost was fourteen times higher than the hybrid system. The researchers concluded that similar sites can be electrified with Wind/PV/DG/Battery system at a low cost and environmentally friendly, which will improve the lifestyle of the community.

Kaabeche & Ibtiouen [22] studied various capacity stand-alone PV/wind/diesel/battery system for rural area in Algeria. In their research focused to optimize the capacity sizes by using iterative method to meet 100% of the energy demand. The proposed model considered energy deficit (ED), energy cost (EC), and net present cost (NPC). The systems, which had 0% energy deficits were compared with economical parameters. The optimization was done by the software developed. They concluded that PV/wind/diesel/battery system is more economically feasible.

Khan et al. [23] conducted study to find out techno economic viability analysis of hybrid system for telecommunication application for four cities in India. The telecommunication load selected for the study was BTS (Base Transceiver Station). The resource assessment had been conducted for solar radiation and wind speed for the selected sites. Six hybrid configurations (i.e. PV/DG, PV/Wind/DG, PV/Wind/DG/Battery, PV/DG/Battery, Wind/DG/Battery, and Wind/DG) were studied. From HOMER simulation, the researcher concluded that PV/Wind/DG/Battery was the best feasible solution both economical and by producing more electricity. The COE of the PV/Wind/DG/Battery was $0.162/kWh.

Maleki and Askarzadeh [24] studied optimal sizing of hybrid system in Iran. The optimization was carried out by discrete harmony search (DHS) and the discrete simulate annealing (DSA) were used to compare results. PV/Wind/DG/Battery, PV/DG/Battery, Wind/DG/Battery, and DG alone were studied. The Wind/DG/Battery was selected as the best economical system.

Ramli et al. [25] conducted a study to find out techno economic viability analysis of hybrid system in Saudi Arabia. The focus of the study was on the hybrid systems photovoltaic (PV) and wind turbine energy production and cost. Both excess and unmet electrical demand were considered. MATLAB and HOMER software were used for technical and financial assessments of the hybrid system. For case study area, the PV were producing more energy than the wind turbine for the same size. The battery and wind turbine were used to meet the demand rise during the night time. The researchers suggested that while selecting PV/wind/Battery system meeting electricity demand with low COE should be considered.

Tesema and Bekele [26] conducted a study to find out techno economic viability analysis of hybrid system for rural community in Ethiopia. Solar and wind resource assessments were conducted. The load assessment was also conducted for 500 households. Boilers and thermal loads were considered for effective utilization of surplus energy. HOMER software was used for the optimization of the system. The configuration considered in the research PV/wind/DG/Battery, DG only and possible grid extension. The HOMER simulation was used to find out the best possible configuration from PV/wind/DG/Battery by using parameters like renewable penetration, low unmet demand, low COE and low diesel consumption. The researcher concluded that hybrid systems can supply energy to off-grid area as grid 24/7.

Photovoltaic powered water pumping systems come up with having lots of advantages, including operational safety, robustness, considerably reduced life-cycle expenses, extended system life and minimal impact on the environment [27], [28].

The photovoltaic pumping system has been the subject of numerous studies regarding its feasibility, performance, and economic viability, and demonstrated that the system can be more cost-effective than diesel generators. For example, Saeed[29] examined irrigation systems aided by solar thermal and solar photovoltaic technology and concluded that these systems could be implemented in small-scale rural farms in sub-Saharan Africa. Additionally, in a remote area of Jordan Badia, Al-Smairan[27] developed the application of two systems to supply power to a water pump. Realizing stand-alone diesel and photovoltaic generator projects is part of this application. Photovoltaic water pumping systems can be more economical in this area than diesel generators, as the author has shown.

Shinde [30] conducted a comparative study between photovoltaic and diesel generators in India for water pumping systems that can supply up to 3 kWp of water to a village. According to the author's finding, photovoltaic assisted water pumping option is more feasible from an economic standpoint.

Alkarrami, [31], investigated the techno-economic performance analysis of stand-alone Wind/ PV/Battery hybrid system for water pumping application in the city of Syrte, Libya, and also Rezk et'al [32] conducted techno-economic performance analysis of a stand-alone photovoltaic/wind energy system with storage applied to the irrigation system of the city of Alminia, Egypt, the study was performed using HOMER software.

To determine which option would be best for this site, Vick and Neal [33] examined the individual performance of solar PV, wind turbine, and off-grid PV/WT hybrid systems for water pumping. A straightforward methodology was described by Diaz-Mendez et al. [34] to compare wind-powered and solar water pumping systems in Spain, Pakistan, and Cuba. Kelley et al.'s study [35] examined the viability of photovoltaic-powered irrigation systems based on location.

A review of research advancements in the field of water pumping systems based on renewable energies (solar, biomass, wind, and PV/WT hybrid, among others) was provided by the authors in [36], and more than a hundred published publications were examined. The authors concluded that using renewable energy, particularly solar and wind power, has a beneficial environmental impact because it significantly lessens reliance on conventional energy.

Gaps Identified

The literature review has shown that hybrid renewable systems are suitable and economical to supply electricity in off-grid areas in various places. From the literature review conducted, HOMER software is widely used for the optimization and simulation of hybrid systems, even though there is wide variation in the renewable energy resource availability and potential, country of application (households, schools, health centers, hotels, and others) and load demand. In the literature review, some literatures consider pumps as a deferrable load. However, in this research, irrigation pump loads will be considered as the primary load unlike other research. The designed system also meets household demand, other institutional loads, and commercial loads.

Table 2. 2. Various techno economic studies summary

Project location	Load type	Sizing	NPC	COE	Software	Reference
Benin	Household, community, and commercial loads	PV-150kW, DG-62.5kVA, Battery-637 kWh	$555,492	$0.207/kWh	HOMER	[10]
Pakistan	Residential and commercial	Wind-15MW, Solar-20MW, Biomass-20MW	$180 Million	$0.05744/kWh	HOMER	[11]
India	Household, commercial, agriculture and community	MHP-50 kW, Biogas-50 kW, Biomass gasifier-40 kW Wind-33 kW, PV-57 kW, Battery-427.20 kWh	$ 825,408	$ 0.092/ kWh	HOMER	[15]
Sri Lanka	Household and Commercial	Wind-40 kW, PV-30 kW, Battery-222 kWh, Gen-25 kW	$553,000,	$0.34/kWh	HOMER	[16]
Bangladesh	Household and Commercial	Biogas-9 kW, PV-10 kW, DG- 20 kW, Bat-25.2kAh	$612,280	$0.28/kWh	HOMER	[17]

Ethiopia	Household and Community	DG–44 kW, Batt–46.24kAh	$201,609	$0.3222/kWh	HOMER	[18]
Colombia	Household and Community	PV 160kW, Wind 10kW, Gen 25kW	$836,210	$0.473/kWh	HOMER	[19]
Malaysia	Large Resort	PV-700kW, Wind-1.25MW, Gen-700kW	$17.15 million	$0.279/kWh	HOMER	[20]
Ethiopia	Household, community, and commercial loads	PV-700kW, Wind-16.5MW, Gen-1122kW	$25M	$0.11/kWh	HOMER	[21]
Algeria	Household and Community	PV-8.5 kW, Wind-1 kW, DG-4.2 kVA, Batt-86.4 kWh	$183,982	$1.30/kWh	HOMER	[22]
Saudi Arabia	Household, community, and commercial loads	PV-400kW, Wind-200kW	$ 4,037,980	$0.329/kWh	HOMER and Mathlab	[25]

According to the table shown in above, the COE is very high. It will not be affordable to the rural households. In this research, the COE will be reduced by integrating productive use of energy (PUE) i.e. irrigation.

2.3. The Application of HOMER Software

HOMER (Hybrid Optimization Model for Multiple Energy Resources) is a micro-power optimization-modeling tool developed by the United States Department of Energy's (DOE)

National Renewable Energy Laboratory (NREL) for the Village Power initiative [37], [38], [39]. The software application may identify system configuration, system components and sizing, resource cost and availability, and the vast array of technology options accessible [40].

2.3.1. Simulation

HOMER simulates a certain system configuration's operation over a year by running hourly time series simulations. HOMER moves through the year one hour at a time, calculating available renewable power, comparing it to electric load, and choosing what to do with excess renewable power in times of excess, or how best to create (or purchase from the grid) additional electricity in times of deficit. After one year of calculations, HOMER determines whether the system meets the user's constraints on quantities such as the fraction of total electrical demand served, the proportion of power generated by renewable sources, or the emissions of certain pollutants. HOMER also computes the quantities needed to calculate the system's life-cycle cost, such as annual fuel consumption, annual generator running hours, estimated battery life, or annual grid power purchased [41].

2.3.2. Optimization

During the optimization process, HOMER simulates a large number of different system configurations, discards the infeasible ones (those that do not satisfy the user-specified constraints), ranks the feasible ones by total net present cost, and presents the feasible one with the lowest total net present cost as the optimal system configuration. The optimization process's purpose is to find the best value for each decision variable that interests the modeler[42].

2.3.3. Sensitivity

In sensitivity analysis, HOMER executes numerous optimizations, each with a different set of input assumptions. A sensitivity analysis determines the sensitivity of the outputs to changes in the inputs. The user enters a range of values for a single input variable in a sensitivity analysis. A sensitivity variable is one for which the user has entered various values. A sensitivity variable can be almost any numerical input variable in HOMER that is not a decision variable [41].

3. MATERIAL AND METHOD

The research area, the sampling method, the research design, data collection, processing, data analysis, modeling and simulation methods were addressed in this section.

3.1. Description of the study area

The selected site for this research is Shima Kebelle, found in Amhara Region, North Shoa Zone, Moret ena Jiru woreda, with a Latitude of 9^{o}52’44’’N and a Longitude of 39^{o}4’16’’E. Its elevation is 1570 meters above sea level. The main economic activities of the community rely on agricultural products, which include fruits and vegetable products, crop cultivation, and animal herding. In the village, there is one primary school, three religious centers, one health post office, one kebele administration office, six small shops, and two restaurants. There are also two diesel mills in the village, although they are not operational during field visits because of high fuel prices. Shima Kebelle has enormous potential for irrigation, but it’s not tapped.

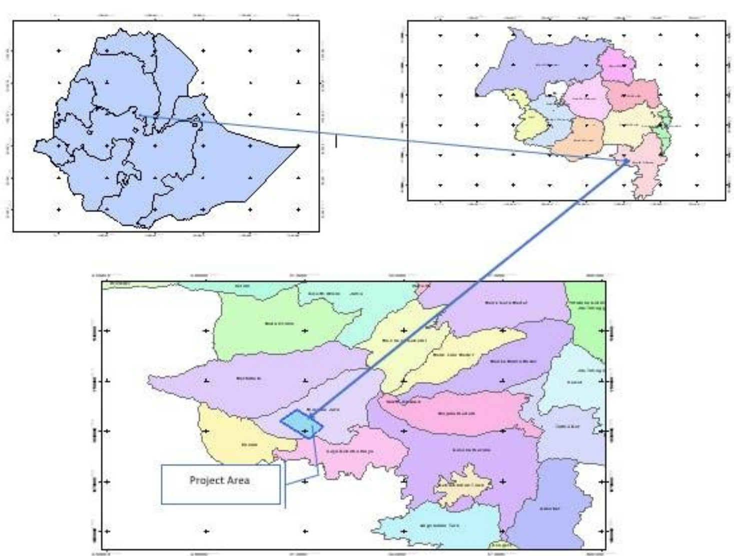

Figure 3. 1. Map of the study area

3.2. Methodology

3.2.1. Research design

Figure 3. 2 shows the overview of methodology which followed in this research.

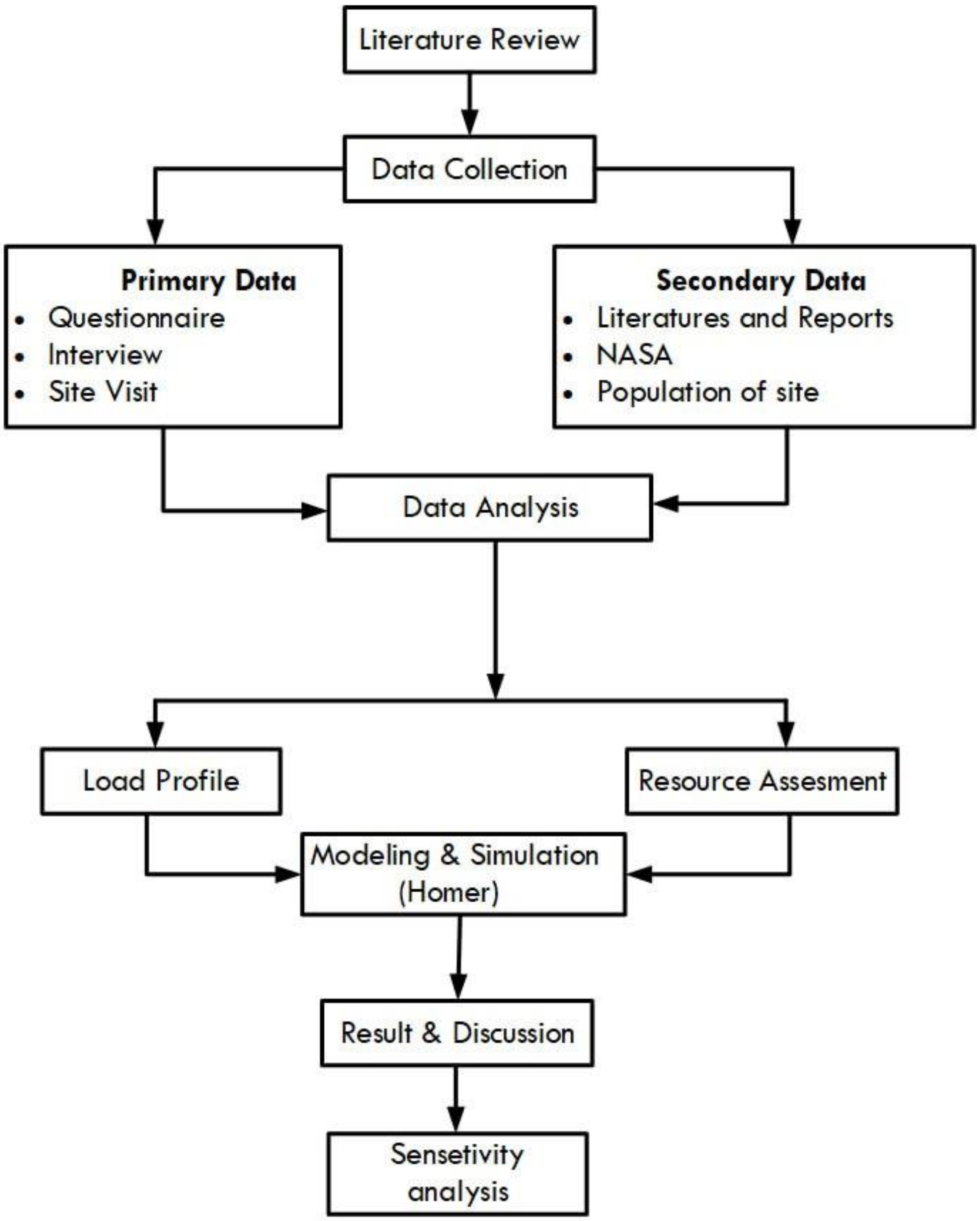

Figure 3. 2. Research design

3.3. Data Collection

The data required for the research were collected from primary and secondary data sources. The data collected enables the researcher to obtain the energy demand of the study area and the renewable energy resources of the site.

3.3.1. Primary data

Primary data are the one collected by the researcher. To collect the primary data, a questionnaire, an interview, and a field visit were used. The data collected include the annual income of households, irrigation hectare size, crop type, irrigation frequency, and others that enable to determine the load profile of the site. The questionnaires are prepared for three groups. The first group is the household level; the second group is the business centers, government bureaus, and religion centers and the third group are the farmers who are practicing irrigation. The participants in the questionnaire were selected using purposively sampling techniques for this study first data about the community was collected from kebele administrators and snow ball (chain sampling) technique was implemented.

The prepared questionnaire was uploaded to the Kobo toolbox. Kobo Toolbox is open-source, free software that anyone can use to collect data on the go. It enables to gather data on the go with mobile devices like tablets or smartphones, in addition to paper and PCs. The result of the questionnaire response can be easily uploaded to Excel from Kobo. This helps to avoid potential errors while copying questionnaire responses from paper to computers. The questionnaire used in this research is attached in Annex I.

3.3.2. Secondary Data

The secondary data is the data collected by other parties important to the research. The secondary data includes metrological data, the number of households, electrical equipment sizing, and various equipment costs. The metrological data for the site was obtained from the nearest metrological station, and its results were compared with online data obtained from NASA. The coordinates are required to get online data from NASA. The coordinates of the site were obtained by using GPS tools. This research also used data from websites, journals, and research papers, which is necessary for the study.

3.4. Electric Load Estimation

The electrical load demand of the area was divided into different sectors, including the household sector, irrigation sector, governmental and institutional sectors, including schools, health centers, and religious places. The total electrical load was obtained from the sectors appliance use and time of utilization; the results of all sectors were summed up to get the total energy demand of the community.

3.4.1. Population forecast of the Village

To reduce load variability and future energy increase, calculating power and population projection is important in this case. Load forecast was done by taking the population growth of the community living in the village.

It makes sense to take population growth into account when planning an energy supply since the demand for a specific location will rise as the population grows. Let's first compute the future population increase in the village using the following formula to take into account the number of community families that increase annually. Given the current population and the growth rate, the formula to determine the future population is [43]:

$$F_P = P_P \times (1 + PGR)^{yrs} \tag{3.1}$$

Where, P_p = The present population of Shima kebele i.e. 2,707,

PGR= population growth rate is 2.5% annually according to the World Bank report [44]

yrs = projection year, 5 years

$$F_p = P_p \times [1 + PGR]^{yrs}$$

$$F_p = 2707 \times [1 + 0.025]^5$$

$$F_p = 3{,}062$$

Considering 5 person per the household, the hybrid mini-grid will be designed to serve 612 households.

3.4.2. Household Electric Load

The household electricity demand was estimated by considering energy-saving appliances such as compact fluorescent humps (CFL), TVs, radios, cook stoves, etc. The wattage of the appliances was taken from the manufacturer's manual.

The community is classified into three classes based on their economic activity; their energy demand also varies, which is lower class, middle class and higher class. The lower-class community was assumed to utilize two light bulbs, one mobile charger and one radio or tape recorder; the middle-class class community was assumed to utilize three light lamps, a mobile charger, a TV and a cook stove; and the higher-class community use a refrigerator and Injera baking mitad in addition to the second class. The decision for their class level was made depending on their annual income, assets available, monthly income and other factors. Through interviewing and researchers' observation, the load demand for homes were estimated. The household heads mentioned their electrical appliance needed and the researcher estimated hours of use and energy demand based on their response. Table 3. 1. shows the daily household energy demand of each class.

Table 3. 1. Household Energy Demand

Household Classification	Appliances	Qty	Wattage	Operation hour	Energy (Wh/day)
Lower Class	Light Lamps	2	13	4	104
	Mobile charger	2	15	2	60
	Radio/tape recorder	1	20	4	80
Total					**244Wh**
Middle Class	Light lamps	3	13	4	156
	Mobile charger	3	15	2	90
	TV	1	70	4	280
	Electric Cookstove	1	1000	1	1000
Total					**1526Wh**
High Class	Light lamps	4	13	4	208
	Mobile charger	4	15	2	120
	TV	1	70	4	280
	Cookstove	1	1000	1	1000
	Refrigerator	1	100	8	800
	Electric Injera mitad	1	4000	0.5	2000
Total					**4408Wh**

3.4.3. Institutional loads

The load demand in institutional sectors encompasses schools, health centers, and religious places. The school load includes lighting for classes and office rooms, desktop computers, copy machines and printers for the existing primary and secondary schools. The health center load demand was estimated for different appliances, primarily a room lighting TV, computer, printer, laboratory microscope, water heater and vaccine freezer.

3.4.3.1. Health Center Load

For a health facility, different loads, such as lighting, laboratory equipment, vaccine refrigerators, sterilizers, etc., operate for different durations throughout the day. Some equipment operates more during the day time than at night time, and vice versa. During the interview, the health center head expressed the center electrical demand based on equipment they want to use and hour of usage when the electric power supply arrive to their village. The health center head listed equipments needed by the center for day to day operation. The following equipments are listed by the head of the health center: primarily a room lighting TV, computer, printer, laboratory microscope, water heater and vaccine freezer. The health center head stated that having electricity to supply these equipments will help them to meet their mission. Table 3. 2 shows the daily energy demand of the health center of the village.

Table 3. 2. Health center Energy Demand

Health center Energy Demand					
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	10	13	4	520
2	Refrigerator	1	100	8	800
3	Microscope	1	20	2	40
4	Sterilizer	1	1000	0.5	500
5	Centrifuge	1	100	2	200
6	Suction pump	1	150	1	150
7	TV	1	70	8	560
8	Mobile charger	10	15	2	300
9	Radio/Tape player	2	20	4	160
10	Printer	1	700	1	700
11	Water Heater	1	1000	1	1000
Total					**4930Wh**

3.4.3.2. Education/School Load

The school load includes lighting for classes and office rooms, desktop computers, copy machines and printers for the existing primary school. During the site visit, the school director expressed the electrical equipments required in order to have good learning and teaching process. the center electrical demand based on equipment they want to use and hour of usage when the electric power supply arrive to their village. In the study, the energy was estimated with the school having fifteen lamps, fifteen mobile chargers, two desktop computers with printers, one television and radio. Table 3. 3 shows the daily energy demand of the school in the village.

Table 3. 3. School Load

			Schools		
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	15	13	2	390
2	Mobile Charger	15	15	2	450
3	Desktop computer	2	400	8	6400
4	Printer	1	700	1	700
5	TV	1	70	2	140
6	Radio	1	20	4	80
Total					**8160Wh**

3.4.3.3. Kebele Administration Office Load

The Kebele chairman stated the electrical equipment the administration office needs. Based the data provided by the kebele chairman, the Kebele administration office was estimated to have four light lamps one computer with a printer and two mobile chargers. Table 3. 4 shows the daily energy demand of the office in the village.

Table 3. 4. Government Office Load

			Government office		
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	4	13	4	208
2	Computer	1	400	4	1600
3	Mobile	2	15	2	60

	Charger				
4	Printer	1	700	1	700
	Total				**1868Wh**

3.4.4. Commercial Electric Load

The commercial load demands encompassed shopping centers, flour milling centers and grocery and restaurant. During the site visit, the business owners expressed the electrical equipments required in order to make their business more productivity. The business owners stated their electrical demand based on equipment they want to use and hour of usage when the electric power supply arrive to their village.

3.4.4.1. Shopping Center Load

The shopping center of the village estimated to have two lamps, two mobile chargers, TV, radio and refrigerator. Table 3. 5 shows the daily energy demand of shop in the village.

Table 3. 5. Shopping Center Load

Shopping Center					
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	2	13	4	104
2	Mobile Charger	2	15	4	120
3	TV	1	70	8	560
4	Radio	1	20	10	200
5	Refrigerator	1	100	8	800
	Total				**1784Wh**

3.4.4.2. Mill load

The mill for the village estimated to have two lamps, two mills and two mobile chargers. Table 3. 6 shows the daily energy demand of the mill in the village.

Table 3. 6. Milling load

Milling					
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**

1	Light Lamps	3	13	4	156
2	Milling machine	2	7500	4	60000
3	Mobile Charger	2	15	2	60
	Total				**60216Wh**

3.4.4.3. Grocery and Restaurant

The grocery and restaurant of village have five lamps, five mobile chargers, LED light, TV and sound system. Table 3. 7 shows the daily energy demand of grocery and restaurant in the village.

Table 3. 7. Grocery and Restaurant

	Grocery and Restaurant				
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	5	13	6	390
2	Mobile Charger	5	15	4	300
3	LED light	1	50	4	200
4	TV	1	70	8	560
5	G-pas/Sound system	1	100	4	400
6	Refrigerator	2	100	8	1600
	Total				**3450Wh**

3.4.5. Church load

In the study area there is only one Orthodox Christian church and the load estimated for the church will encompass 15 light lamps, two sound systems and two mobile chargers based on the discussion with the church admistratator. Table 3. 8 shows the daily energy demand of the church.

Table 3. 8. Church Load

	Church				
	Appliances	**Qty**	**Wattage**	**Operation hour**	**Energy (Wh/day)**
1	Light Lamps	15	13	4	780
2	Sound System	2	100	4	800
3	Mobile	2	15	2	60

Charger	
Total	**1640Wh**

3.4.6. Irrigation Electric load

3.4.6.1. Irrigation energy requirement determination

In this study, the energy required for irrigation was calculated based on the water requirement of the crop, the nature of the soil, the weather conditions of the area, and the cropping season. To calculate crop water requirements (CWR), reference evapotranspiration (ETo), irrigation water requirements (IR), and irrigation schedule using climate data, rainfall, crop type, and soil type, the FAO developed the decision-support software application CROPWAT 8.0 [61], [62]. By offering general data for various crop features, soil conditions, and regional climate, the application aids in the optimization of irrigation schedules and the estimation of scheme water supply for diverse crop patterns under irrigated and rainfed situations.

Using the GPS coordinates of the sites, the NASA website is used to retrieve the climate information for the research region. The following information was gathered from the NASA website: mean monthly relative humidity (%), sunshine hours (h), maximum and minimum monthly temperatures (°C), wind speed (km/h), effective rainfall (mm), and rainfall data (mm). Table 3. 9. shows the weather data for Shima kebele which are important for the CROPWAT.

Table 3. 9. Weather data of the area [45]

Month	**Min Temp (ºC)**	**Max Temp (ºC)**	**Humidity %**	**Wind (km/day)**	**Sun Hours**	**Rad (kWh/m²/day)**	**Rain (mm)**	**Eff Rain (mm)**
January	2.9	23.6	7	200	8.8	6.88	9.4	0.0
February	4.2	25.2	7	210	8.5	6.96	28.8	7.3
March	5.6	25.6	8	210	8.0	6.04	44.4	16.6
April	7.2	24.4	10	195	8.0	5.37	74.4	35.5
May	8.2	23.8	10	203	8.0	4.85	39.8	13.9
June	8.9	24.8	10	171	8.0	3.53	44.1	16.5
July	8.7	22.8	10	153	7.5	2.65	101.0	56.8
August	8.5	21.8	11	131	7.5	2.75	108.2	62.6
September	7.5	20.5	10	148	7.5	4.04	66.1	29.7
October	3.6	20.4	8	208	7.5	6.17	22.2	3.3
November	2.5	21.5	8	208	8.5	7.00	19.6	1.8

December	1.1	21.9	7	195	8.0	7.25	13.8	0.0
Average	5.7	23.0	9	186	8.0	5.29	47.67	20.33

Lemons, tomatoes, and onions are all grown by farmers in the study region with the use of irrigation. The FAO Manual was used in this study to identify the crop's features, and the results were integrated with the CROPWAT program. Crop coefficient, rooting depth, length of plant growth stages, critical depletion and yield response factor are among the parameters of the crop that were obtained from the FAO manual [46].

The FAO CROPWAT 8.0 model's soil characteristics provide precise data on the soil close to the climate station, such as the availability of the total amount of moisture, the initial moisture depletion, the maximum rooting depth, and the maximum rain infiltration rate. During the site survey, the soil of the study area is black clay soil. Table 3.10 shows the soil data for the study area.

Table 3. 10. General Soil data for Black clay soil [46]

Description	**Quantity**
Total available soil moisture (FC - WP)	200.0 mm/meter
Maximum rain infiltration rate	30 mm/day
Maximum rooting depth	900 centimeters
Initial soil moisture depletion (as % TA)	50 %
Initial available soil moisture	100.0 mm/meter

Evapotranspiration is the combined water loss from the plant surface (transpiration) and water loss from the soil (evaporation). The CROPWAT software uses the FAO Penman-Monteith equation to calculate evapotranspiration (ETo) which derives most of its factors from weather data [47], [48], [49], [50], [51].

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma\frac{900}{\mathrm{T} + 273}\mathrm{U2}(\mathrm{es} - \mathrm{ea})}{\Delta + \gamma(1 + 0.34\mathrm{U2})} \tag{3. 2}$$

Where:

ETo=Reference evapotranspiration (mm/day),

Rn=Net radiation at the crop surface ($MJ/m^2/day$),

G=soil heat flux density ($MJ/m^2/day$), T=mean daily air temperature (°C),

U2=Wind speed at 2m height (m/sec),

es=saturation vapor pressure (kPa),

ea=actual vapor pressure (kPa),

es-ea=saturation vapor pressure deficit (kPa),

Δ= slope vapour pressure curve (kPa/°C),

γ=psychrometric constant (kPa/°C)

The Crop water requirement is expressed by the rate of ET in mm/day which is equal to the amount of water lost from a planted field by ET. The CRW can be estimated from crop evapotranspiration (ETc), which can be calculated by using the following equation [47], [48], [49], [50], [51]:

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc} \tag{3. 3}$$

Where,

ETc = Crop Evapotranspiration (mm/day),

ETo = Reference Crop Evapotranspiration (mm /day),

Kc = Crop coefficient

3.4.6.2. Irrigation Water Requirement

The primary factor in the planning, creation, and management of irrigation and water resource systems is the irrigation requirement (IR). When operating and managing irrigation systems, it is crucial for policymakers and decision-makers to allocate water resources as efficiently as possible. Inadequate management of irrigation needs can result in inadequate storage reservoir capacity, inefficient water consumption, a decrease in the irrigated area, and higher development expenses. Therefore, the following equation determines the irrigation requirement [47], [48], [49], [50], [51]:

$$\mathrm{IRn} = \mathrm{ETc} - (\mathrm{Pe} + \mathrm{Ge} + \mathrm{Ws}) + \mathrm{LR} \tag{3. 4}$$

Where,

IRn = Net irrigation requirement (mm),

ETc = Crop evapotranspiration (mm),

Pe = Effective dependable rainfall (mm),

Ge = Groundwater contribution from water table (mm),

Ws = Water stored in the soil at the beginning of each period (mm) and

LR = Leaching requirement (mm)

i. Crop coefficient

The crop's Kc will change over the growing period, which can be separated into four distinct stages: beginning, crop development, midseason, and late season, as a result of ET variations over the growth stages. Kc reflects a combined effect of four important parameters that set the crop apart from reference grass and it encompasses crop height, albedo (reflectance) of the crop-soil surface, evaporation from the soil, and canopy resistance.

ii. Scheduling

The right amount of water to irrigate with and the right time to water are determined by irrigation scheduling. To create irrigation schedules for various administration scenarios and water supply plans, the CROPWAT model computes the ET0, CWR, and IRs.

3.4.6.3. Onion Water Requirement

Onions are widely produced in the study area. The farmers consider onion as their main cash crop plant. During the site survey, around twenty-five hectares i.e. 50% the irrigated land were covered by onion. CROPWAT generates the following plant characteristics, which are studied by FAO. Table 3. 11. shows the different characteristics of onion.

Table 3. 11. Onion characteristics [46]

Stage	Initial	Development	Middle	Late	Total
Length (days)	20	30	30	15	95
Kc values	0.70	0.7	1.05	0.95	
Rooting Depth (m)	0.25	0.25	0.6	0.60	
Critical depletion	0.30	0.25	0.45	0.50	
Yield response factor	0.80	0.40	1.20	1.00	1.00
Crop height (m)			0.30		

The CROPWAT software will calculate the onion crop water requirement based on soil data, weather data, and plant characteristics. The table below shows the water requirements in various states of the crop. The crops are expected to be planted in mid-October. Table 3. 12. shows the water requirement of onion at various stages of their growth.

Table 3. 12. Onion Water Requirement

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
October	2	Initial	0.70	3.54	35.2	0.0	21.2
October	3	Initial	0.70	3.53	35.8	0.2	38.6
November	1	Development	0.74	3.70	37.0	0.8	36.2
November	2	Development	0.86	4.33	43.3	0.6	42.7
November	3	Development	1.00	4.89	48.9	0.4	48.5
December	1	Middle	1.09	5.26	52.6	0.1	52.4
December	2	Middle	1.09	5.17	51.7	0.0	51.7
December	3	Middle	1.09	5.32	53.5	0.0	58.5
January	1	Late	1.07	5.35	53.5	0.0	53.5
January	2	Late	1.01	5.21	36.6	0.0	36.4

The CROPWAT has also determined the crop irrigation schedule. During the calculation, the following factors are assumed to be considered the timing of irrigation at 100% depletion and field efficiency at 70% [48]. Table 3. 13 show the irrigation requirement and schedules.

Table 3. 13. CROPWAT result of Onion Irrigation Schedule

Date	Day	Stage	Rain	Net irr (mm)	Gr. Irr (mm)
15 Oct	1	Initial	0	28.2	40.3
20 Oct	6	Initial	0	18.5	26.5
26 Oct	12	Initial	0	22.5	32.2
1 Nov	18	Initial	0	25.1	35.9
10 Nov	27	Development	0	32.1	45.9
20 Nov	37	Development	0	43.0	61.4
1 Dec	48	Development	0	55.2	78.9
13 Dec	60	Middle	2.3	56.0	80.0
25 Dec	72	Middle	0	58.5	83.6
6 Jan	84	End	0	60.5	86.5
17 Jan	End	End	0		

The net irrigation water requirement and gross irrigation water requirement is calculated by the CROPWAT to give us the total amount of water in the specific period of the time. To determine the pump size, the gross irrigation water requirement is used. Table 3. 14 computes the water requirement obtained in the Table 3. 13 to daily water requirement. The daily water requirement is calculated by dividing the gross irrigation requirement to the number of days between each irrigation schedule.

Table 3. 14. CROPWAT result of Onion daily requirement

Date	**Day**	**Gr. Irr (mm)**	**Numbers of days**	**Daily water (mm)**
15 Oct	1	40.3	5	8.06
20 Oct	6	26.5	5	5.3
26 Oct	12	32.2	5	6.44
1 Nov	18	35.9	8	4.48
10 Nov	27	45.9	9	5.1
20 Nov	37	61.4	10	6.14
1 Dec	48	78.9	11	7.17
13 Dec	60	80.0	11	7.27
25 Dec	72	83.6	11	7.6
6 Jan	84	86.5	11	8.65
17 Jan	End			

The daily water irrigation requirement is calculated in mm, so it should be converted to cubic meters per day, which is used to calculate the energy required by the pump. The following formula will be used to convert the mm/day to m^3/day.

$$Required\ Irrigation\ Water\ \left(m^3/_{day}\right) = Crop\ water\ requirment\ \left(mm/_{day}\right) \times Irrigation(ha) \times 10 \quad (3.\ 5)$$

The maximum daily water requirement is used to determine the cubic water to which the onion require during the late stage of the plant.

$$Required\ Irrigation\ Water\ for\ onion \left(m^3/_{day}\right) = \left(8.65\ mm/_{day}\right) \times (25\ ha) \times 10$$

$$Required\ Irrigation\ Water\ \left(m^3/_{day}\right) = 2162.5\ m^3/_{day}$$

3.4.6.4. Tomatoes Water Requirement

Tomatoes are widely produced in the study area. The farmers consider tomatoes as their main cash crop plant. During the site survey, around twenty-five hectares i.e. 50% of the irrigate farm were covered by tomatoes or the remaining farm. CROPWAT generates the following plant characteristics which are studied by FAO. Table 3. 15 shows the characteristics of Tomatoes on the various growth stages.

Table 3. 15. Tomatoes characteristics [46]

Stage	Initial	Development	Middle	Late	Total
Length (days)	20	35	35	15	105
Kc values	0.60	0.60	1.15	0.80	
Rooting Depth (m)	0.25	0.25	1.00	1.00	
Critical depletion	0.30	0.30	0.40	0.50	
Yield response factor	0.50	0.60	1.10	0.80	1.05
Crop height (m)			0.60		

The CROPWAT software will calculate the tomatoes crop water requirement based on soil data, climate weather data, and plant characteristics. Table 3. 16 shows the water requirement in various states of the crop. The crops are expected to be planted mid of October.

Table 3. 16. CROPWAT result of Tomatoes Water Requirement

Month	Decade	Stage	Kc Coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req mm/dec
October	2	Initial	0.60	3.03	30.2	0.0	16.0
October	3	Initial	0.60	3.02	30.2	0.2	28.6
November	1	Development	0.65	3.26	32.6	0.8	27.0
November	2	Development	0.82	4.08	40.8	0.6	35.5
November	3	Development	0.99	4.86	48.6	0.4	43.
December	1	Middle	1.16	5.57	55.7	0.1	52.4
December	2	Middle	1.21	5.70	57.0	0.0	51.7
December	3	Middle	1.21	5.86	58.6	0.0	58.5
January	1	Middle	1.21	6.02	60.2	0.0	53.5
January	2	Late	1.12	5.75	57.5	0.0	36.4
January	3	Late	0.93	4.92	49.2		

The CROPWAT has also determined the crop irrigation schedule. During the calculation, the following factors are considered the timing of irrigation at 100% depletion and field efficiency 70% [48]. Table 3. 17 below the irrigation requirement and schedules.

Table 3. 17. CROPWAT result of Tomatoes Irrigation Schedule

Date	Day	Stage	Rain	Net irr	Gr. Irr
15 Oct	1	Initial	0	28.6	40.8
21 Oct	7	Initial	0	23.8	34.0

29 Oct	15	Initial	0	29.5	42.1
8 Nov	25	Development	0	39.1	55.8
19 Nov	36	Development	0	51.9	74.2
1 Dec	48	Development	0	69.0	98.5
16 Dec	63	Middle	0	85.2	121.7
31 Dec	78	Middle	2.3	83.1	118.8
15 Jan	93	Late	0	85.1	121.5
27 Jan	End	End	0		

The net irrigation water requirement and gross irrigation water requirement is calculated by the CROPWAT give us the total amount of water in the specific period of the time. To determine the pump size, the gross irrigation water requirement is used. Table 3. 18 computes the water requirement obtained in the Table 3. 17 to daily water requirement. The daily water requirement is calculated by dividing the gross irrigation requirement to the number of days between each irrigation schedule.

Table 3. 18. CROPWAT result of Tomatoes daily requirement

Date	**Day**	**Gr. Irr**	**Number of days**	**Daily Water (mm)**
15 Oct	1	40.8	6	6.8
21 Oct	7	34.0	7	4.85
29 Oct	15	42.1	9	4.67
8 Nov	25	55.8	10	5.58
19 Nov	36	74.2	11	6.74
1 Dec	48	98.5	14	7.03
16 Dec	63	121.7	14	8.69
31 Dec	78	118.8	14	8.48
15 Jan	93	121.5	11	11.04
27 Jan	End			

The daily water irrigation requirement calculated in mm, so it should be converted to cubic meter per day which used to calculate the energy required by the pump. The following formula will be used to convert the mm/day to m^3/day

$$Required\ Irrigation\ Water\ \left({m^3}/{day}\right) = Crop\ water\ requirment\ \left({mm}/{day}\right) \times Irrigation(ha) \times 10$$

The maximum daily water requirement is used to determine the cubic water to which the tomatoes require during the late stage of the plant.

$$Required\ Irrigation\ Water\ for\ tomatoes \left({m^3}/{day}\right) = \left(11.04\ {mm}/{day}\right) \times (25\ ha) \times 10$$

$$Required\ Irrigation\ Water\ for\ tomatoes \left({m^3}/{day}\right) = 2760\ {m^3}/{day}$$

3.4.6.5. Daily Water Requirement

The total water required for the irrigation

$$Required\ Irrigation\ Water\ for\ Irrigation = Required\ Irrigation\ water\ for\ onion + Required\ water\ for\ tomatoes$$

$$Required\ Irrigation\ Water\ for\ Irrigation = 2162.5\ {m^3}/{day} + 2760\ {m^3}/{day}$$

$$Required\ Irrigation\ Water\ for\ Irrigation = 4922.5\ {m^3}/{day}$$

The pump operation time is equivalent to the average sun hour of the site 7 hours per day. The pump pumping capacity for irrigation is equal to amount of daily irrigation water required for irrigation divided by the sun hour or operation time.

$$Pump\ discharge\ \left({m^3}/{hr}\right) = Daily\ irrigation\ requirment\ \left({m^3}/{day}\right) \div Daily\ Operation\ ({hr}/{day})$$

$$Pump\ discharge\ \left({m^3}/{hr}\right) = 4922.5 \div 7$$

$$Pump\ discharge\ \left({m^3}/{hr}\right) = 703.2\ {m^3}/{hr}$$

This water demand doesn't include human drinking and livestock which is currently met by spring water. The spring water currently meets the drinking water demand sufficiently.

3.4.6.6. Power Required for Irrigation

The irrigation conveyance in the study area that will be used is open canal. The losses are calculated by using Manning's equation [52], [53]. Figure 3. 3 shows the schematic size of the irrigation canal that will used for conveying the irrigation water from the source to the farm.

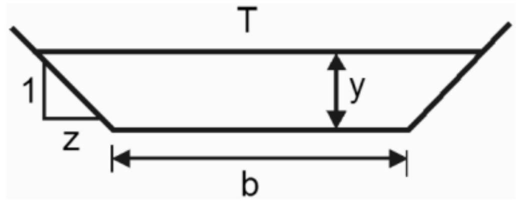

Figure 3. 3. Schematic drawing of irrigation conveyance

The conveyance size is assumed b=1m, z=1m and y=0.3m.

$$A = (b + zy)y \quad (3.\ 1)$$

$$P = b + 2y\sqrt{(1 + z^2)} \quad (3.\ 2)$$

$$T = b + 2zy \quad (3.\ 3)$$

Where y- Depth (m)

A- Area (m^2)

P- wetted perimeter (m)

T- Top width (m)

The flow rate in the open channel is calculated [53]

$$Q = \frac{1}{n} A {R_h}^{2/3} S_f^{1/2} \quad (3.\ 4)$$

The frictional slope of canal is calculated by [53].

$$S_f = \frac{h_f}{L} \quad (3.\ 5)$$

n-The roughness and Manning’s from the table for natural channel (clean) is 0.030.

Q-flow rate (m^3/s)

A - cross sectional area (m^2)

R_h-Radius, $R_h = {}^{Area}/_{Wetted\ Perimeter} - (m)$

S_f - frictional slope of the canal

h_f-friction loss

L- length of the canal

$$A = (b + zy)y$$

$$A = (1 + 1 \times 0.3)0.3$$

$$A = 0.39$$

$$P = b + 2y\sqrt{(1 + z^2)}$$

$$P = 1 + 2 \times 0.3\sqrt{(1 + 1^2)}$$

$$P = 1.85$$

$$R_h = {}^{Area}/_{Wetted\ Perimeter} \qquad (3.\ 6)$$

$$R_h = {}^{0.39}/_{1.85}$$

$$R_h = 0.21$$

$$Q = \frac{1}{n} A {R_h}^{2/3} S_f^{1/2}$$

$$S_f = \sqrt{\frac{Qn}{AR_h^{2/3}}}$$

$$S_f = \sqrt{\frac{0.195 \times 0.030}{0.39 \times 0.21^{2/3}}}$$

$$S_f = 0.206$$

The pump will deliver to command area via canal which is 100 m obtained from the site survey. Then the water will flow to farm by gravity. Site survey pictures is attached in the Annex III.

$$S_f = \frac{h_f}{L}$$

$$h_f = S_f L$$

$$h_f = 20.6m$$

The total head of the pump is the sum of elevation difference between pumping position and the canal losses.

$$Total\ head = Head\ due\ Elevation\ difference + friction\ losses$$

$$Total\ head = 40m + 24.4m$$

$$Total\ head = 60.6m$$

Once the total head and the pump discharge are calculated, the pump will be selected from the pump datasheet. The pump considered for this study is the Grundfos pump [54]. From the pump data sheet, the pump recommended to perform the task is LS 300-200-489D with an impeller size of 406.5 mm. The figure below shows the performance and technical data of the pump. From the figure, the motor capacity is 150kW.

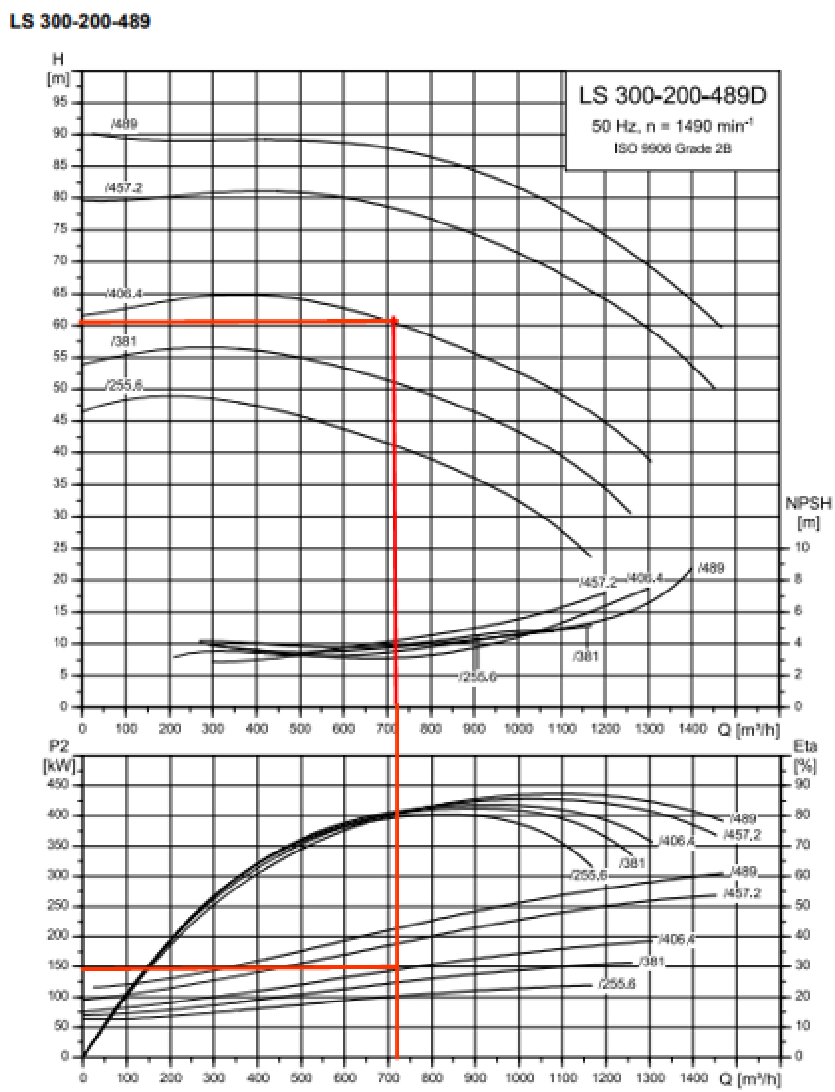

Figure 3. 4. Performance and technical data of LS-300-200-489D

The irrigation scheme's energy demand was obtained by considering the size of the farm, the average crop water requirement, which encompasses losses by evaporation and percolation and the number of plantations per cycle per year. The results obtained were compared with the diesel pumps that they currently use. The drinking water in the village does not require power because it is gravity-fed from a spring.

Table 3. 19. Irrigation load

	Irrigation				
	Appliances	**Qty (Set)**	**Wattage (kW)**	**Operation hour**	**Energy (kWh/day)**
1	Pumps	1	150	7	1,050
	Total				**1,050**

3.5. Summary of Load Assessment Result

Table 3. 20 illustrates the total amount of energy required in the village considering the household, institutional, irrigation and commercial electrical energy demands.

Table 3. 20. Summary of Load Assessment Result

Load category	Classification	No.	Energy (kWh/day)	Total Energy (kWh/day)
Households (HH)	Lower level (75%)	459	0.244	111.996
	Middle level (20%)	122.4	1.526	186.7824
	Higher level (5%)	30.6	4.408	134.8848
Business Shops		2	1.784	3.568
Churches		2	1.64	3.28
School		1	8.16	8.16
Health centers		1	4.93	4.93
Milling House		1	60.216	60.216
Grocery and Restaurant		1	3.45	3.45
Gov't Office		1	1.868	1.868
Irrigation		1	1,050	1,050
Total				**1,568 kWh**

3.6. Conceptual design of the study

In a hybrid energy system, two or more main energy sources (either renewable or non-renewable) are joint so that when the capacity of one energy source is exhausted, the other energy sources can step in and bring reliable electricity. The hybrid energy system put forth in this study consists of a solar PV system, wind turbine, generator, and battery storage. By dropping fuel bills, fuel transportation costs, operating expenses and carbon emissions, hybrid systems beat traditional diesel generator systems. In this hybrid system, the diesel generator will be used as a standby or backup. Figure 3. 5 shows the schematic representation of the system proposed in this study.

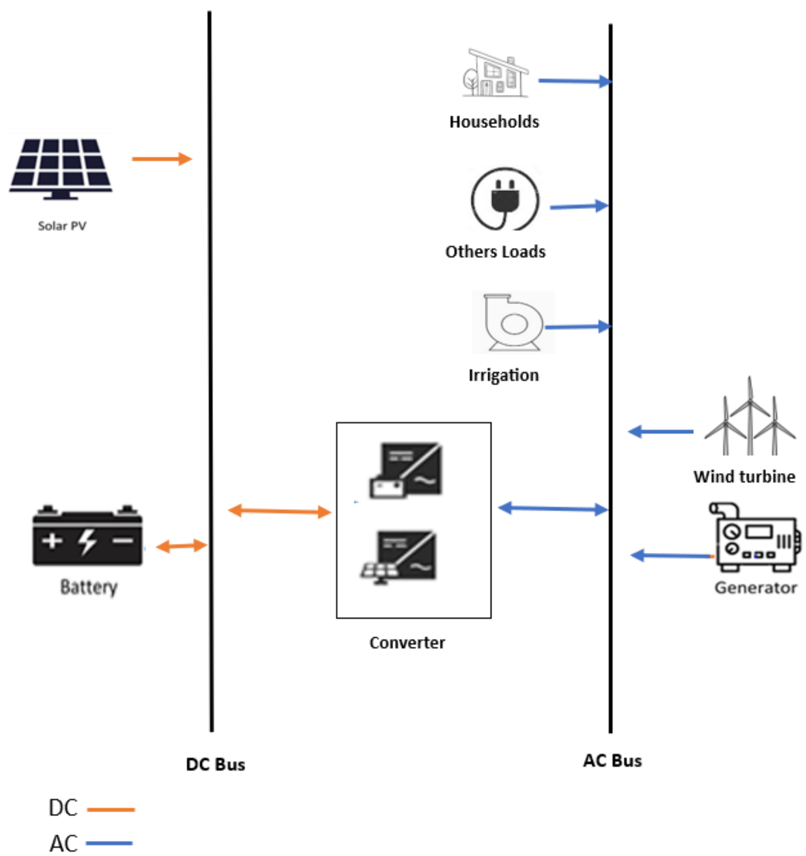

Figure 3. 5. Conceptual design of the study

In the situation of this research, hybrid mini-grid system often refers to a arrangement that mixes solar PV with another form of power source, such as diesel generators or batteries or wind turbines. This combination lets for more consistent and continuous energy supply. The key components of a solar hybrid system include:

1. **Solar PV Panels:** It change sun ray into electricity. It is the main energy source of the mini-grid.
2. **Energy Storage (Batteries):** It are used to store excess electricity produced throughout sunny hours. This stored energy can be utilized during hours of low sunlight or high demand.
3. **Backup Power Source:** The backup power system considered in this research is diesel generator. Where solar energy alone is insufficient, it will integrated with system to ensure a continuous and reliable power supply.
4. **Wind Turbine:** In this project, wind turbine is also be used. It generates electricity and supply to the system when there is wind available.
5. **Inverters/ Controllers:** These components manage the flow of electricity between the solar panels, batteries, and other power sources. Inverters convert DC power generated by solar panels into AC power used in most electrical appliances. It also montitor the battery status.
6. **Monitoring and Control Systems:** These systems help optimize the performance of the hybrid system by monitoring energy production, consumption, and storage, allowing for efficient management.

By combining solar power with other energy sources and incorporating storage solutions, solar hybrid systems provide a more stable and flexible energy supply, making them suitable for various applications, including mini-grids for rural electrification.

3.7. Solar Resource of the Village

The Global Solar Atlas is used to collect solar resources. It is a free online platform developed by Solargis with the support of the World Bank and the Energy Sector Management Assistance Program (ESMAP) [55]. Figure 3. 6 have presented the monthly solar irradiation of the study area. From the data, the site has huge potential for electricity production from solar energy. The average daily radiation of the study area is 5.29 kWh/day/m^2. The maximum and minimum solar radiation is obtained on December and July, i.e., 7.25 and 2.65 kWh/day/m^2 respectively.

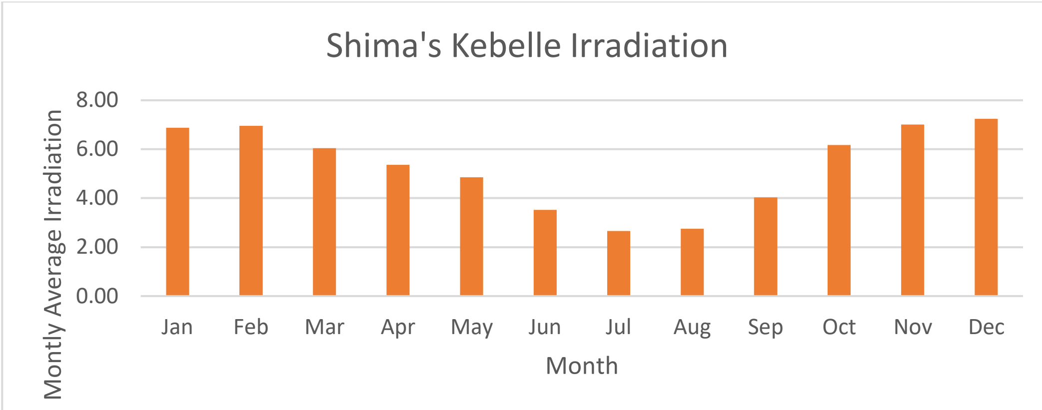

Figure 3. 6. Monthly solar average radiation of Shima kebele

3.8. Wind resource of the village

Wind speed of the study area is obtained from NASA. The maximum and the minimum wind speed is in October and August i.e. 4.51m/s and 2.46 m/s respectively at 10 meter. The average wind speed is 3.61 m/s [45]. Table 3. 21 shows the average wind speed of the study area.

Table 3. 21. Average Monthly Wind Speed

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
Wind Speed (m/s)	3.72	3.86	3.88	3.88	4.18	2.99	2.6	2.46	3.07	4.51	4.24	3.94

4. OPTIMIZATION INPUT DATA TO HOMER

The proposed hybrid system for this research includes a PV system, wind turbine, battery pack, diesel generator, and convertor. Renewable energy resources, demand load assessment, technical specification of system components, and economical parameters of system components are needed to perform simulation, optimization, and sensitivity analysis for a given system.

4.1. Renewable Energy Sources

The renewable energy sources that are considered for the study area are solar and wind resources. The details of the renewable energy assessment are presented in the sections 3.7 and 3.8.

4.2. Demand Load Input

4.2.1. Primary loads

To design a power generation and supply system, the electrical load demand is an important factor. Section 3.4 shows the energy demand of each group of the community calculated which includes households, business centers, government offices, religious centers, school, and health center. These loads are considered as primary load/ electrical load which utilizes the all energy producing components to meet the primary loads so that there is no unmet demand. The primary loads don't have seasonal variation.

4.2.2. Irrigation Load

Irrigation electric demand is very high compared to other loads. The pumps operate from 9AM to 3PM for seven hours. This is because during these hours, the solar irradiation is high so irrigation load can be effectively met by the solar PV. The summary of the daily load profile of the site is shown in the Table 4. 1. Irrigation takes up to 66.9 % of the daily load.

The farmers of the site don't irrigate during the rainy season, they grow non horticulture crops like Teff, Maize, Chickpea, Wheat, and others. Table 4. 1 shows the hourly aggregated consumption of the different loads in the village for the dry season. The dry season includes from October to May and the rainy season covers from June to September. During the rainy season, the farmers will use the rainwater to irrigate their crops instead of pumps. So the irrigation loads will be omitted in this season. The detail of the load profile is attached on Annex II.

Table 4. 1. Load Profile of dry and rainy season

Time	HHs, Community and Others in kWh	Irrigation in kWh	Total of dry season	Total of wet season
0:00	1.34	0	1.34	1.34
1:00	1.34	0	1.34	1.34
2:00	1.34	0	1.34	1.34
3:00	1.34	0	1.34	1.34
4:00	1.34	0	1.34	1.34
5:00	1.34	0	1.34	1.34
6:00	1.41	0	1.41	1.41
7:00	6.75	0	6.75	6.75
8:00	5.15	0	5.15	5.15
9:00	34.59	150	184.59	34.59
10:00	34.59	150	184.59	34.59
11:00	34.59	150	184.59	34.59
12:00	94.59	150	244.59	94.59
13:00	34.59	150	184.59	34.59
14:00	34.59	150	184.59	34.59
15:00	34.59	150	184.59	34.59
16:00	22.31	0	22.31	22.31
17:00	6.19	0	6.19	6.19
18:00	30.99	0	30.99	30.99
19:00	34.05	0	34.05	34.05
20:00	33.97	0	33.97	33.97
21:00	33.95	0	33.95	33.95
22:00	1.38	0	1.38	1.38
23:00	1.33	0	1.33	1.33
Total	**489.65**	**1,050**	**1,568**	**489.65**

Figure 4. 1 shows the consumption of daily energy of the two major energy consumer of the village. Irrigation consumes 66.9% of the energy and the remaining is consumed by households, mill, church, grocery and restaurant, shop, school, health center and government office.

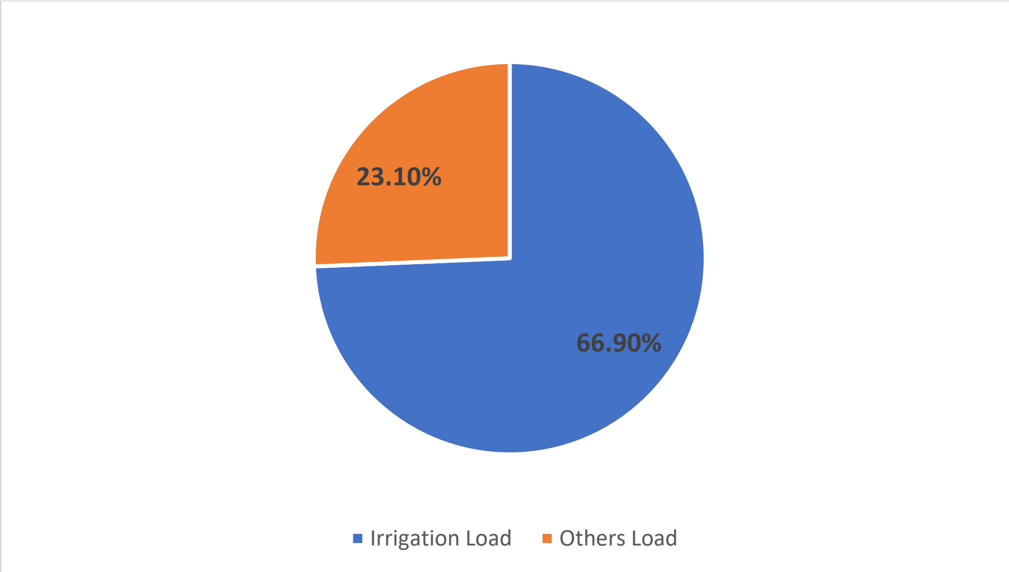

Figure 4. 1. Percentage of daily energy of dry season consumption

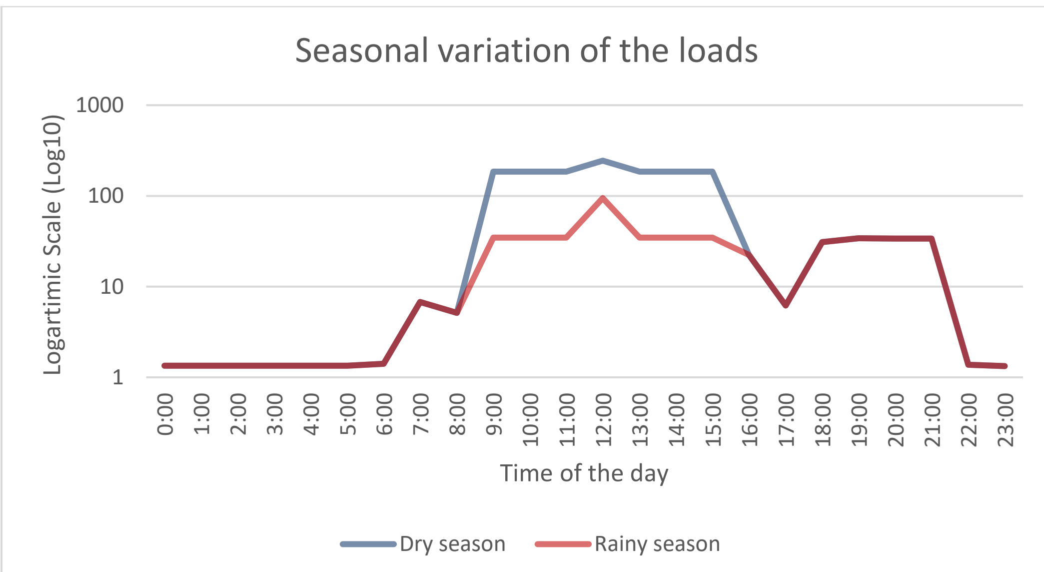

Figure 4. 2. Seasonal variation of the daily loads

To have a better visual presentation, the Y-axis of the figure above is changed to logarithmic to base 10.

4.3. Basic components

The basic components of the hybrid system include electricity generation, storage and converter. The electricity generation is either from renewable or non-renewable energy sources. The renewable energy sources studied in this research are solar and wind which uses solar PV and wind turbine to produces electricity, respectively. The non-renewable energy source used in this research is diesel generators.

4.3.1. Solar panels

The solar PV modules convert the solar irradiation to electricity. The solar PV modules produce DC electricity by using inverter/converter, it will be changed to AC electricity. The solar PV panels selected for this research is Jinko Solar model JKM550M-72HL4-BDVP. The technical specification of the panels is listed in the Table 4. 2 [56] .

Table 4. 2. Solar PV technical specification

Parameter	**Value**
P_{max}	550Wp
V_{mpp}	41.51V
I_{mpp}	13.25A
V_{oc}	50.11V
I_{sc}	14.01A
De-rating factor	85%
Life time	30 years
Operating temperature	-40^{o}C -85^{o}C
Module efficiency	22.07%
Temperature coefficients of P_{max}	-0.30%/^{o}C
Temperature coefficients of V_{oc}	-0.25%/^{o}C
Temperature coefficients of I_{sc}	-0.046%/^{o}C

HOMER use the equation below to calculate the power produced by the PV[42]. It uses the kWp of the panels not m^2.

$$P_{PV} = Y_{PV} f_{PV} (\frac{G_T}{G_{T,STC}})(1 + \alpha_P (T_C - T_{C,STC})) \quad (4.1)$$

$Where\ Y_{PV}$ − Rated capacity of the PV array under STC [kw)

f_{PV} − PV derating factor

G_T − The solar radiation incident on the PV array in the current condition [%]

$G_{T,STC}$ − The incident radiation at STC which is equal to 1 kW/m^2

α_P − The temperature coefficient of the power [%/°C]

T_C − PV cell temperature in the current condition [°C]

$T_{C,STC}$ − PV cell temperature under standard test condition which is 25°C

The temperature of PV have effect on the power produced by the solar panels. As the temperature increases, the power produced by the PV is reduced. The formula below is used to calculate the PV temperature [42].

$$T_C = T_a + G_T(\frac{T_{c,NOCT} - T_{a,NOCT}}{G_{T,NOCT}})(1 - \frac{\eta_c}{\tau\alpha}) \quad (4.2)$$

T_C − PV cell temperature in the current condition [°C]

T_a − Ambient temperature [°C]

$T_{C,NOCT}$ − Nominal operating cell temperature should be reported by manufacturer, which is defined as the cell temperature at an incident radiation of 0.8 kW/m^2

$T_{a,NOCT}$ − Ambient temperature where the NOCT is defined

G_T − The solar radiation incident on the PV array in the current condition [%]

$G_{T,NOCT}$ − Solar radiation equals to 0.8 kW/m^2

$\eta_{mp,STC}$ − Maximum power point efficiency under the test condition

τ − Solar transmittance

α − Solar absorbance

4.3.2. Wind turbines

Wind turbines operate by converting the kinetic energy of the wind into rotational kinetic energy in the turbine and finally into electrical energy. The wind turbine selected for this research is manufactured by Qingdao Henryd Wind Power Equipment Co., Ltd model FD12-30kW [57].The technical specification of the wind turbines is listed in the table below.

Table 4. 3. Wind turbine technical specification

Parameter	Value
Rated power	30kW
Number of blades	3

Hub height	30 m
Wind rotor diameter	12 m
Starting wind speed	3 m/s
Cut-off wind speed	25 m/s
Rated wind speed	12 m/s
Speed governing method	Electric yawing
Parking method	Electric yaw + manual brake/auto brake by controller
Lifetime	20 years

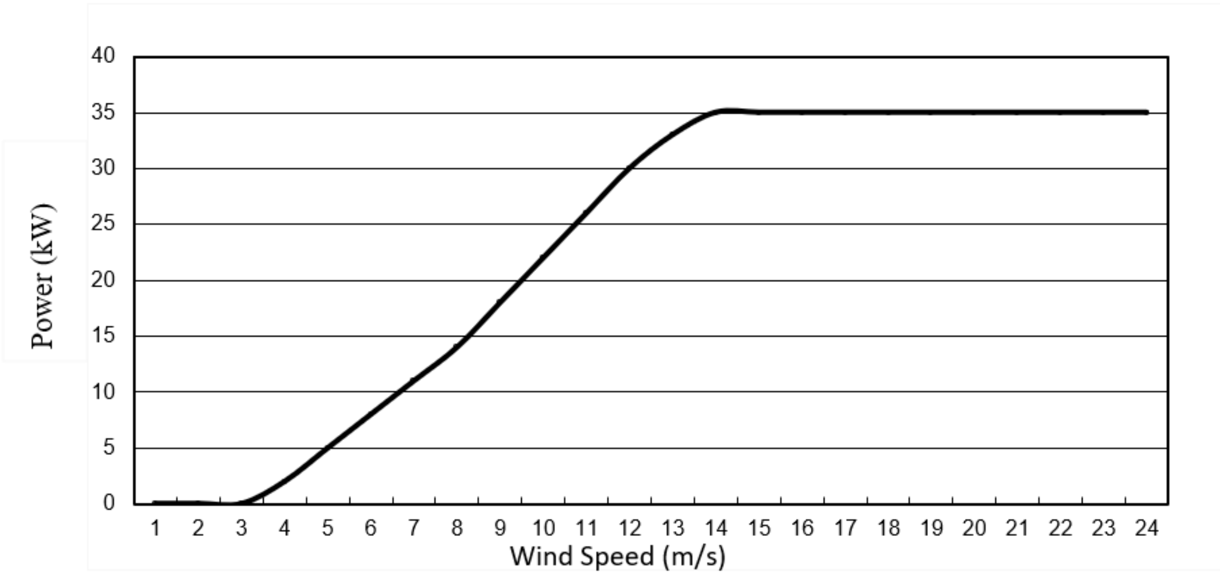

Figure 4. 3. Wind Turbine Power Output curve

The main parameters affecting the converted energy are the wind velocity and the swept area of the turbine. Generally, the mechanical power of the wind turbine is calculated by using the following equation [38]

$$P_{avail} = \frac{1}{2}\rho A v^3 C_{pmax} \tag{4. 3}$$

$\rho - density\ of\ air (kg/m^3)$

$A - swept\ area\ (m^2)$

$v - wind\ speed\ (m/s)$

$C_{Pmax} - power\ coefficient/Betz's\ coefficient\ (C_{Pmax} = 0.59)$

$The\ actual\ power\ produced\ by\ the\ wind\ turbine$

$P_w = 0.5 * \eta_g \eta_w \rho A v^3 C_{Pmax}$

HOMER calculates the wind turbine's power output every hour under standard temperature, air density, and pressure conditions. It takes altitude into account when estimating wind turbine output since it impacts air density, which affects wind turbine output [42].

$$\frac{\rho}{\rho_0} = \left(1 - \frac{Bz}{T_0}\right)^{g/_{RB}} \left(\frac{T_0}{T_0 - Bz}\right) \tag{4. 4}$$

Where as $\rho - density\ of\ air$

ρ_0 − Air density under standard conditions which are sea level and 15 ℃

T_0 − Standard temperature, 288.16 K

B − Lapse rate, the rate of temperature change according to altitude, 0.00650 K/m

z − Altitude

$g - gravity\ {}^{m}/_{s^2}$

R − Gas constant, 287 J/kgK

4.3.3. Battery

The energy production of renewable energy sources fluctuates with time; sometimes they produce more energy than the demand at that specific time, and sometimes they do not meet the demand at that specific time. The battery stores the excess power produced by the renewable energy sources and supplies it during the shortage. The battery selected for this research is Lithium-Ion battery manufactured by Zwayn Energy model ESS-10240 [58]. The Technical specification of the battery is listed in the Table 4. 4.

Table 4. 4. Battery technical specification

Parameter	Value
Product capacity	51.2V200Ah
Nominal voltage	51.2V
Nominal capacity	200Ah
Max charge current	100A
Max discharge current	100A
Round trip efficiency	95%
DoD	80%
Life cycle	5000 times @80%DoD

The state of charge (SOC) of the battery is the total of all daily charge and discharge transfers. As a result, SOC is stands for current integration, which expresses the ratio of available current capacity to nominal capacity [4].

$$SOC = 1 - \int \frac{i\eta dt}{C_n} \tag{4. 5}$$

Where $i - charging\ current$

$\eta - coulombic\ efficiency\ which\ is\ the\ ratio\ of\ charging\ energy\ to\ discharging$

$energy\ necessary\ to\ reclaim\ the\ previous\ capacity$

$t - time$

$C_n - Nominal\ capacity$

It is important to understand on how rapidly it can be charged or discharge, how deeply it can be discharged without causing harm, and how much energy can cycle through it before it needs to be replaced. The capacity of charging and discharging calculated as follows [59]

Battery charging

$$P_b(t) = P_b(t-1)(1-\sigma) + \left(P_{bh}(t) - \frac{P_{bl}(t)}{\eta_{bi}}\right) * \eta_{bb} \tag{4. 6}$$

Battery discharging

$$P_b(t) = P_b(t-1)(1-\sigma) + (P_{bh}(t)/\eta_{bi} - P_{bl}(t)) \tag{4. 7}$$

$Where\ P_b - battery\ energy\ in\ time\ interval$

P_{bh} – total energy generated by PV array

P_{bl} – load demand in time interval

$\eta_{bi} - inverter\ efficiency$

$\eta_{bb} - battery\ charging\ efficiency$

$\sigma - self\ discharge\ factor$

4.3.4. Generator

The diesel generator serves as back-up if the energy demand is unmet with renewable energy source and battery storage. The CAPEX of the generator is relatively small compared to the

OPEX of the generator due to the most fuel consumption. Generator fuel consumption can be calculated by [42].

$$F = F_0 Y_{gen} + F_1 P_{gen} \quad (4.8)$$

$F - Fuel\ consumption\ (L)$

$F_0 - generator\ fuel\ curve\ intercept\ coeffcient\ (L/h/kW)$

$F_1 - generator\ fuel\ curve\ slope\ (L/h/kW)$

$Y_{gen} - Rated\ capacity\ of\ generator\ (kW)$

$P_{gen} - output\ of\ the\ generator\ (kW)$

The Generator selected for this research is Cummins diesel generator supplied by Pulita New Energy model HTD-60GFS [60]. The Technical specification of the generator is listed in the table below.

Table 4. 5. Generator Technical specification

Parameter	Value
Rated Power	60kW/75kVA
Rated voltage	400V/230V
Rated frequency	50Hz
Rated speed	1500 rpm
Rated current	104 A
Fuel consumption (g/kWh) 100% of load	205 g/kWh
Fuel consumption (L/h) 100% of load	15.2L/h
Life time	20,000h

4.3.5. Convertor

In this research, a power converter was employed to maintain the energy flow between the AC and DC components. The selected converter has the capability of a bi-directional converter that connects the DC and AC buses and converts the DC voltage to the AC voltage needed to power the load. The converter selected for this research is Growatt model SPF 10000T DVM [61]. The Technical specification of the converter is listed in the table below.

Table 4. 6. Converter technical specification

Parameter	Value
Rated power	10kW
Inverter efficiency	88%

Solar charger efficiency	98%

4.4.4.4. Component cost

Most components that are used for the research are not easily available in locally. In this research, the component costs are obtained from different suppliers who have good experience in supplying and delivering. To get the final cost of the components, additional cost like supplementary goods (mounting structure of PV, wind turbine tower, cables, connectors….), transportation cost (sea and land), taxes (duty, VAT, welfare…), estimated installation costs were added to the supplier cost. The final cost of the equipment are used as the capital cost in HOMER simulation. Table 4. 7 shows the capital cost, replacement cost, and O&M costs of components of the system.

Table 4. 7. Component cost

Description of component	**Solar PV system**	**Wind turbine**	**Battery**	**Converter**	**Generator**
Capital cost	USD 620/kW	USD 70,000/turbine	USD 400/kW	USD 400/kW	USD 19,200/Gen
Replacement cost	USD 400/kW	USD 55,000/turbine	USD 300/kW	USD 300/kW	USD 15,000/Gen
O&M cost	USD 10/year	USD 70/year/kW	---	---	USD 0.2/ hr

4.5.4.5. HOMER Economic Analysis

HOMER computes net present cost (NPC) and levelized cost of energy (LCOE) of the project in order to select the most feasible combination of system. NPC is the present value of all costs of installing and operating that component over the project duration minus the present value of all revenues earned over the project lifetime [42]. The NPC is calculated by using the formula below [37].

$$NPC = \frac{C_{ANN,TOT}}{CRF(i,N)} \tag{4. 9}$$

Where $C_{ANN,TOT}$ is annualized total system cost, i is the annual real interest rate, N is life cycle of the system in years, CRF (i,N) is the recovery factor. CRF(i,N) is calculated by this formula[37].

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{4. 10}$$

LCOE is the average cost useful energy produced by the system [42] LCOE is calculated by using the formula below [37], [40].

$$LCOE = \frac{C_{ANN,TOT}}{E_{Load\ Served}} \tag{4. 11}$$

5. RESULT AND DISCUSSION

This chapter presents the results obtained during the course of the work and research findings as well as their respective discussions, and various justifications.

The hybrid system considered in this research consists of PV, wind turbine, generator, battery and converter as stated in the above section. Figure 5. 1 shows the hybrid system of considered for the modeling.

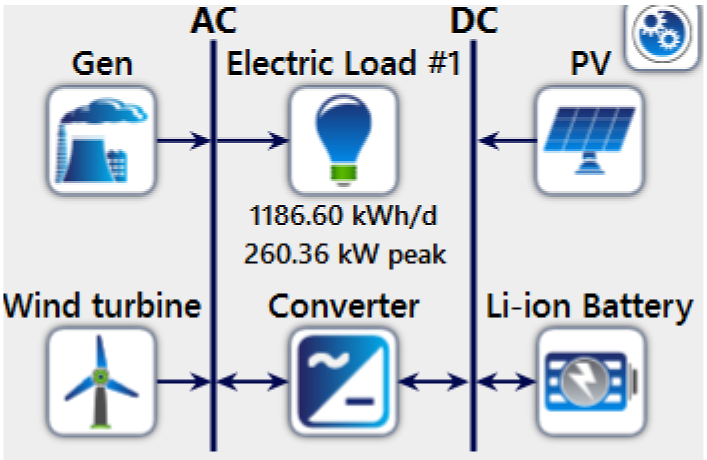

Figure 5. 1. Schematic picture of the Hybrid

5.1. HOMER simulation result and discussion

Following modeling, numerous combinations of available renewable energy sources, along with their initial capital cost, total net present cost, energy per kWh cost, overall system configuration, and component sizes that fit the load demand will be obtained. The simulation results include each component size, the expenses of each system design, and the overall net present cost. The simulation result has two classifications, i.e., categorized and overall. The overall filter provides the HOMER simulation results overall configurations. The categorized filter shows the top-ranked or least NPC configuration for each possible category system configuration.

5.1.1. Simulation result

The simulation results of eight possible configurations of the system are presented below as categorized simulation results. The categorized filter shows the top-ranked or least NPC configuration for each system configuration category. Table 5. 1 shows the categorized HOMER simulation results.

Table 5. 1. HOMER categorized simulation results

PV(kW)	30kW Wind Turbine	Generator (kW)	Battery (kWh)	Converter (kW)	NPC ($)	COE ($)	Operating Cost ($/year)	Initial Capital ($)
313		180	879	283	$537,087	$0.09594	$10,16	$405,674
299	1	180	768	282	$595,442	$0.106	$10,321	$462,020
	15	300	2,005		$2.03M	$0.363	$54,579	$1.32M
		240	478		$2.30M	$0.411	$168,138	$125,267
1,127	2	180			$2.43M	$0.434	$112,229	$979,507
1,276		180			$2.58M	$0.461	$127,536	$933,048
	10	300			$3.96M	$0.706	$244,375	$796,000
		300			$4.60M	$0.821	$348,150	$96,000

5.1.1.1. Selected Configuration (PV-Gen-Battery)

This scheme consists of 313 kW solar PV, 180 kW generator, 879 kWh battery and 283 kW converter so that it can meet the primary. This configuration has the least NPC and COE. The system NPC is USD 537,087 and COE of USD 0.09594/kWh. The solar PV produces 636,233 kWh/year (98.5%) and the generator produces 9,770 kWh/year. The consumption of the primary load is 433,042 kWh/yr. The system produces 186,538 kWh/year (28.9%) excess electricity. The excess electricity is resulted from solar energy production in the rainy season (i.e. June, July, August and September) on which the irrigation load is not available and also dry season in the hours where irrigation is not taking place. There is unmet demand and capacity shortage of 67.1 kWh/yr (0.015%) and 403 kWh/yr (0.093%) respectively. The renewable energy penetration of the system is 97.7%. The dispatch strategy selected is load following.

Production	kWh/yr	%
PV	636,233	98.5
Gen	9,770	1.51
Total	646,004	100

Consumption	kWh/yr	%
AC Primary Load	433,042	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	433,042	100

Quantity	kWh/yr	%
Excess Electricity	186,538	28.9
Unmet Electric Load	67.1	0.0155
Capacity Shortage	403	0.0930

Quantity	Value	Units
Renewable Fraction	97.7	%
Max. Renew. Penetration	3,880	%

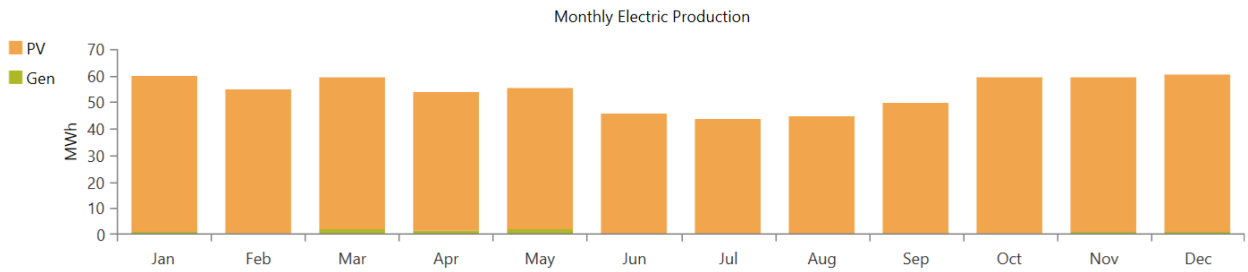

Figure 5. 2. Monthly Electricity Generation of PV-Gen-Battery

5.1.1.2. Selected configuration NPC of scenario 1

NPC is a method used to evaluate the lifetime cost of a project or system by considering various factors such as capital costs, replacement costs, operation and maintenance (O&M) costs, fuel costs, and salvage value. The system NPC of the selected is USD 537,087 and COE of USD 0.09594/kWh.

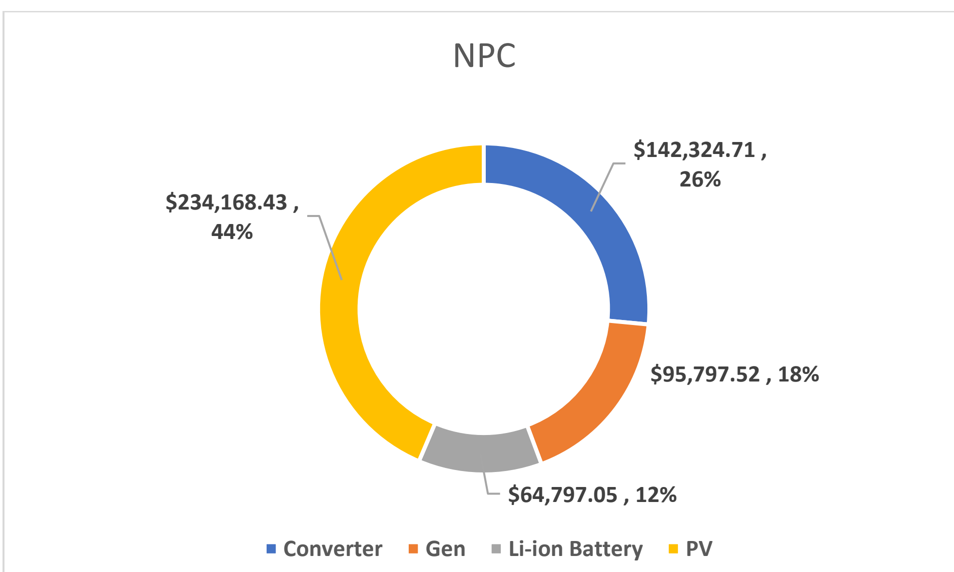

Figure 5. 3. NPC of each component

5.1.1.3. PV Generation

The total electricity production of the PV is 636,233 kWh/yr. From the figure below, the production of PV gets lower in the rainy season. The during those time, the load meet by diesel generator or battery.

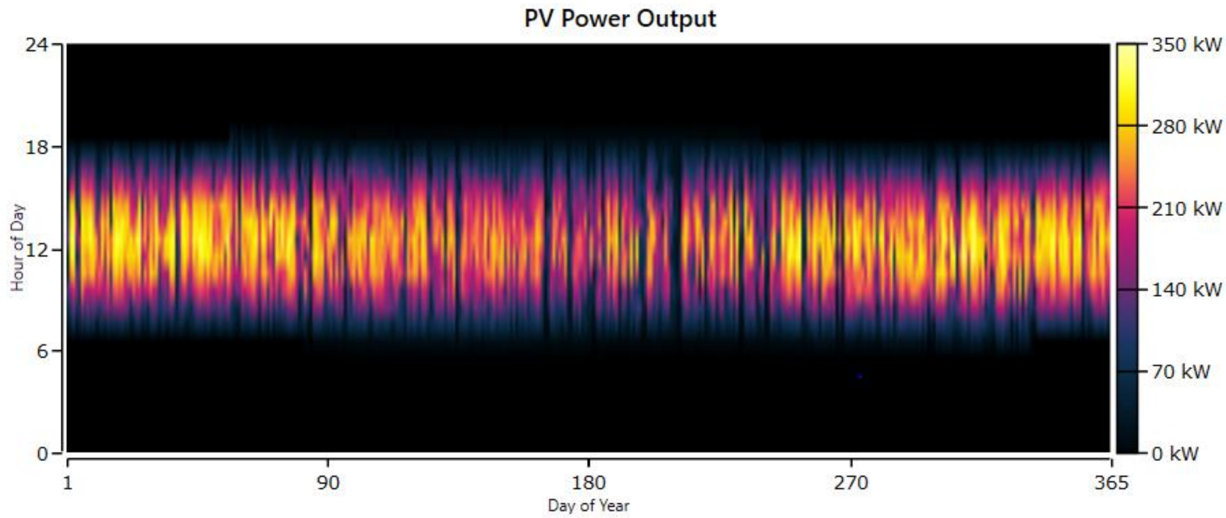

Figure 5. 4. PV power output

5.1.1.4. Diesel Generator

The total electricity production of the diesel generator is 9,770 kWh/yr. It operates for 169 hrs/yr. The fuel consumption is lt/yr. It mostly operates during the daytime when the PV production lowers and there are also some times when it operates during the night time. The yearly fuel consumption is 2,473 liters. The generator doesn't operate in the rainy season because the irrigation doesn't take place.

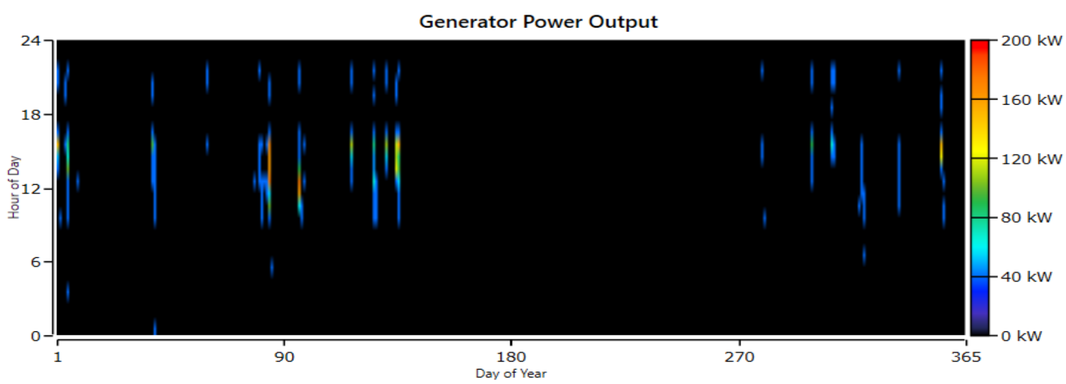

Figure 5. 5. Generator power output

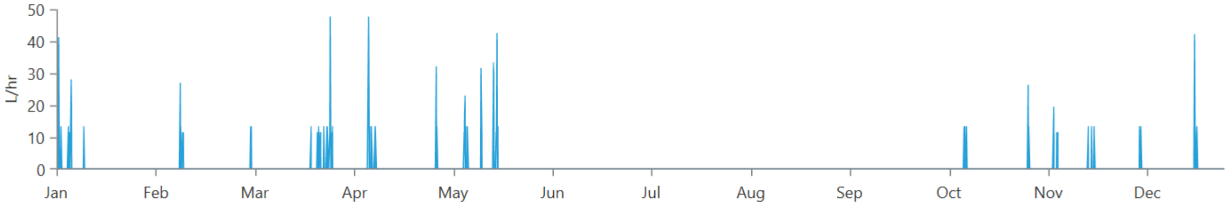

Figure 5. 6. Fuel consumption of the generator

5.1.1.5. Battery

The battery capacity is 879 kWh. Its autonomy is 14.2 hrs. The energy input to the battery is 84,027 kWh/yr and its output is 79,970 kWh/yr. As shown in the figure below, for most period of the time of the year the battery is fully charged during the daytime and 20-30% discharged during the night. During the rainy season, the battery is almost full in the daytime and it consumes around 30% of it during the night.

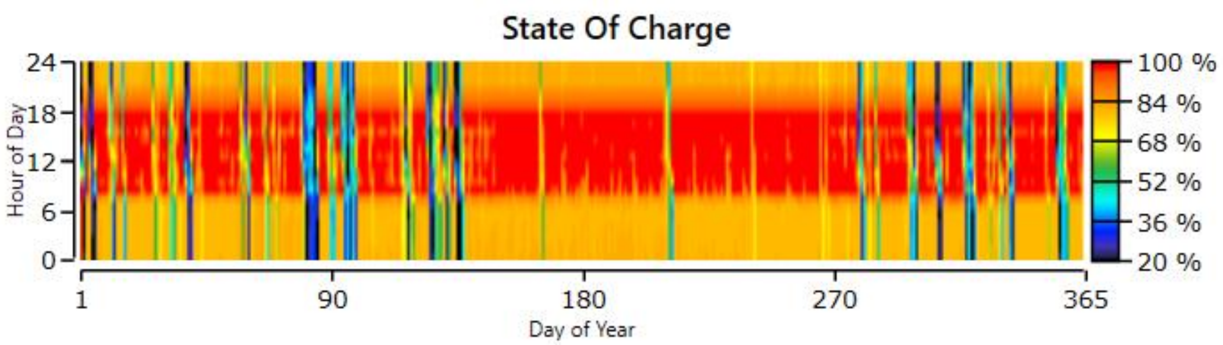

Figure 5. 7. Battery State of Charge

There is flexibility in load management with irrigation load since it can vary from day to day or from one hour to the next. By permitting an annual capacity shortage, two scenarios are examined in this study.

- With 1% capacity shortage: In this scenario, a 1% capacity shortage is allowed in this simulation, meaning 1% annual energy demand will not be met. The system design will meet 99% of the energy demand.
- With 2% capacity shortage: In this scenario, a 2% capacity shortage is allowed in this simulation, meaning 2% annual energy demand will not be met. The system design will meet 98% of the energy demand.

5.1.2. Scenario 1: With 1% capacity shortage

The simulation results of eight possible configurations of system are presented below as categorized simulations. The categorized filter shows the top-ranked or least NPC configuration for each system configuration category. **Error! Reference source not found.**Table 5. 2 shows the categorized HOMER simulation results.

Table 5. 2. HOMER categorized simulation results

PV (kW)	10kW Wind Turbine	Generator (kW)	Battery (kWh)	Converter (kW)	NPC ($)	COE ($)	Operating Cost ($/year)	Initial Capital ($)
343		60	922	228	$494,108	$0.0885	$9,886	$366,305
317	1	60	947	272	$557,287	$0.0999	$9,152	$438,974
	15	240	2,005	206	$2.00M	$0.358	$54,190	$1.3M
1,179		120		208	$2.03M	$0.362	$79,911	$992,447
1,282	2	120		217	$2.10M	$0.375	$91,265	$920,223
		240	265	41.6	$2.30M	$0.411	$169,643	$105,827
	5	240			$3.53M	$0.631	$240,323	$426,800
		300			$4.60M	$0.821	$348,208	$96,000

5.1.2.1. Scenario-1: Selected Configuration (PV-Gen-Battery)

This scheme consists of 343 kW solar PV, 60 kW generator, 922 kWh battery and 228 kW converter so that it can meet the primary. This configuration has the least NPC and COE. The system NPC is USD 494,108 and COE of USD 0.0885/kWh. The solar PV produces 698,628 kWh/year and the generator produces 7,769 kWh/year. The consumption of the primary load is 431,941 kWh/yr. The excess electricity is resulted from solar energy production in the rainy season (i.e. June, July, August and September) on which the irrigation load is not available and also dry season in the hours during which irrigation is not taking place. The annual fuel consumption is 1,966 litre. There is unmet demand and capacity shortage of 1,168 kWh/yr (0.27%) and 4,418 kWh/yr (1.02%) respectively. The renewable energy penetration of the system is 98.2%. The dispatch strategy selected is load following.

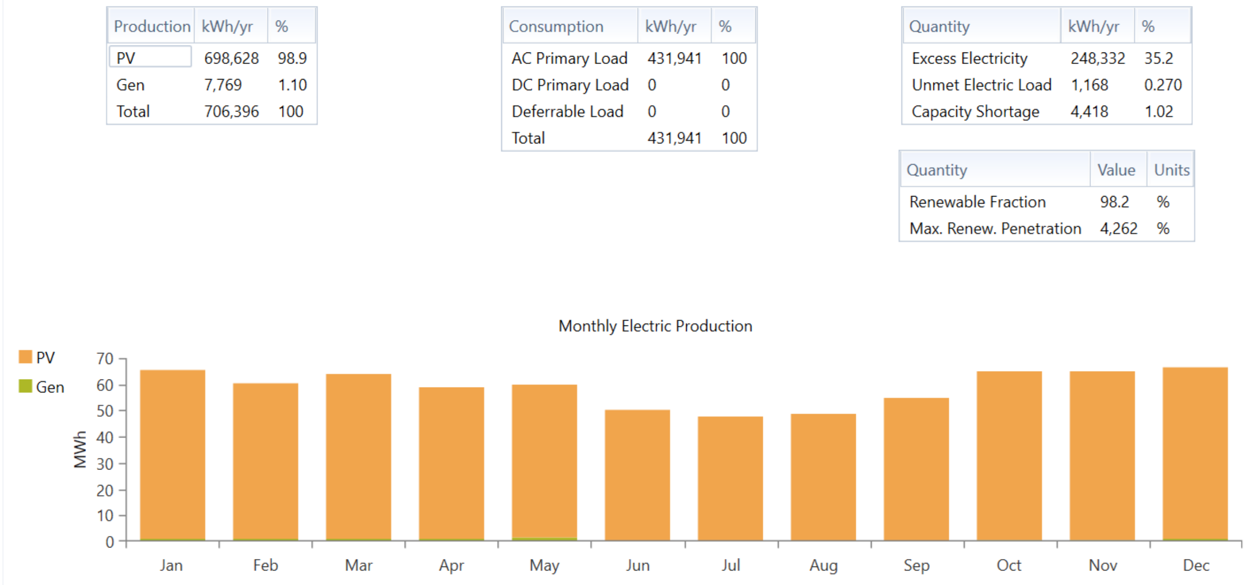

Figure 5. 8. Monthly Electricity Generation of PV-Gen-Battery

5.1.3. Scenario 2: With 2 % capacity shortage

The simulation results of eight possible configurations of the system are presented as categorized simulation results. The categorized filter shows the top-ranked or least NPC configuration for each system configuration category. Table 5. 3 shows the categorized HOMER simulation results.

Table 5. 3. HOMER categorized simulation results of scenario-2

PV (kW)	30kW Wind Turbine	Generator (kW)	Battery (kWh)	Converter (kW)	NPC ($)	COE ($)	Operating Cost ($/year)	Initial Capital ($)
319		60	768	228	$477,902	$0.0859	$10,319	$344,508
306	1	60	649	227	$534,666	$0.0961	$10,419	$399,970
897	2	120		198	$1.86M	$0.333	$81,135	$813,667
956		120		207	$1.93M	$0.344	$93,881	$713,782
	15	180	1,920	206	$1.97M	$0.353	$52,982	$1.28M
		240	265	41.6	$2.30M	$0.411	$169,643	$105,827
	5	240			$3.53M	$0.631	$240,323	$426,800
		240			$3.99M	$0.716	$302,650	$76,800

5.1.3.1. Scenario-2: Selected Configuration (PV-Gen-Battery)

This scheme consists of 319 kW solar PV, 60 kW generator, 768 kWh battery and 228 kW converter so that it can meet the primary. This configuration has the least NPC and COE. The system NPC is USD 477,902 and COE of USD 0.0859/kWh. The solar PV produces 649,836 kWh/year and the generator produces 10,378 kWh/year. The annual fuel consumption is 2,627 litre. The consumption of the primary load is 430,587 kWh/yr. There is unmet demand and capacity shortage of 2,522 kWh/yr (0.58%) and 8,836 kWh/yr (2.06%) respectively. The renewable energy penetration of the system is 96.2%. The dispatch strategy selected is load following.

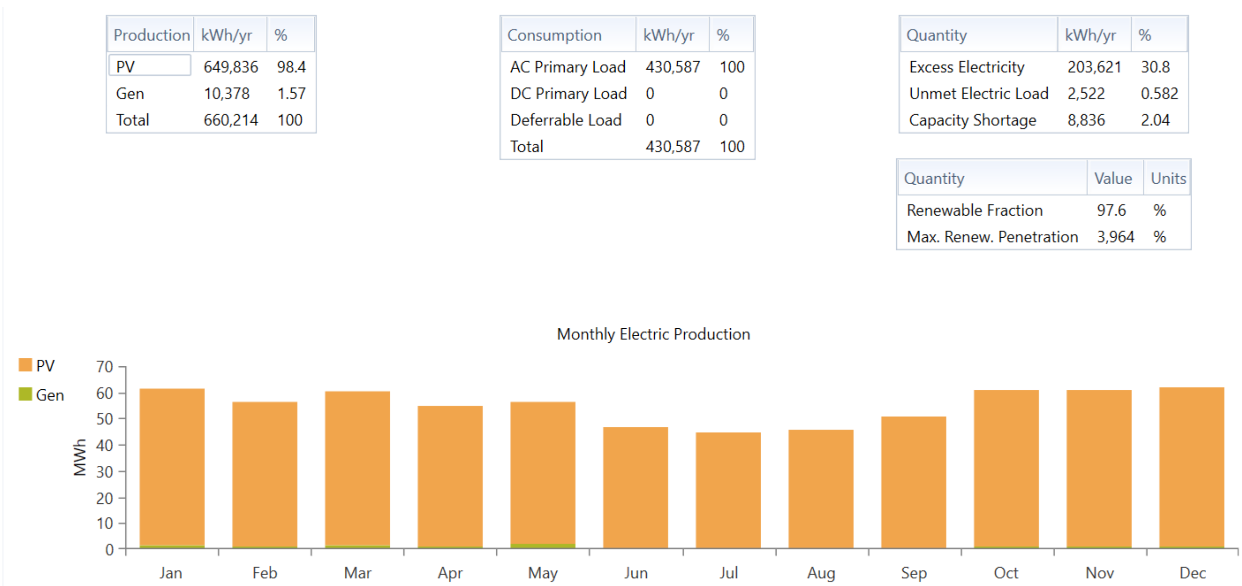

Figure 5. 9. Monthly Electricity Generation of PV-Gen-Battery

5.1.4. Comparison between scenarios

The comparison between each scenario is shown table below.

Table 5. 4. Comparison between scenarios

Scenario	System sizing	NPC ($)	COE ($)	Annual Fuel consumption	GHGs Emission (kg/yr)
Base Scenario	PV- 313 kW Gen-180 kW Battery-879 kWh	$ 537,087	$ 0.0953/kWh	2,473 liters	CO_2- 6,536 kg/yr Others- 67.34 kg/yr
Scenario 1	PV-343 kW Gen-60kW Battery- 922 kWh	$ 494,107	$ 0.0885/kWh	1,966 liters	CO_2-5,198 kg/yr Others- 53.5 kg/yr

Scenario 2	PV -319 kW Gen-60 kW Battery-768 kWh	$ 477,902	$ 0.08585/kWh	2,627 liters	CO_2-6,944 kg/yr Others- 71.5 kg/yr

Scenario 1 is selected in this research because of its low fuel consumption and GHGs emissions. One of the main challenges of the study area is access to diesel and high diesel costs. Flexibility in load management, particularly with irrigation demand, provides an opportunity to maximize the operation of the hybrid solar system while minimizing the issues associated with diesel backup and high prices.

5.1.5. Energy Generation and Consumption Trend

The generation and consumption of the system are illustrated by using two cases.

- **Case 1:- Rainy Season**

By considering sample week (i.e. August 10-16), it can be observed that the generator doesn't operate the whole time. The PV can supply the daily load and charge the battery starting from 6 AM to 11 AM. The battery has supplied the load from 6 PM to 5 AM.

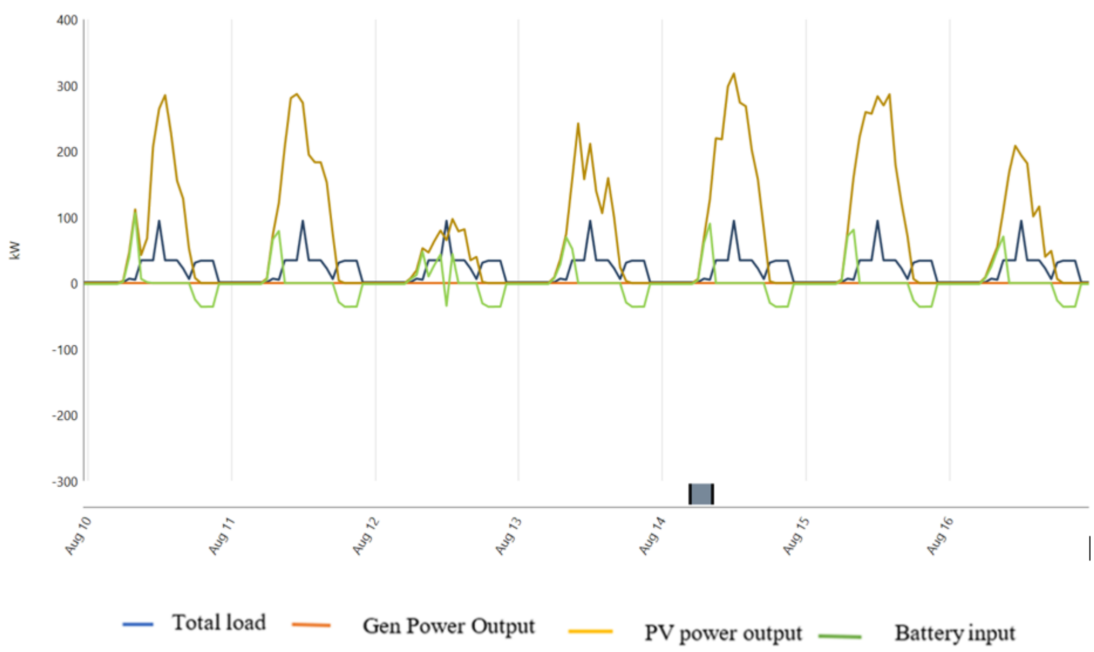

Figure 5. 10. Generation and Consumption of rainy season (August 10 - 16)

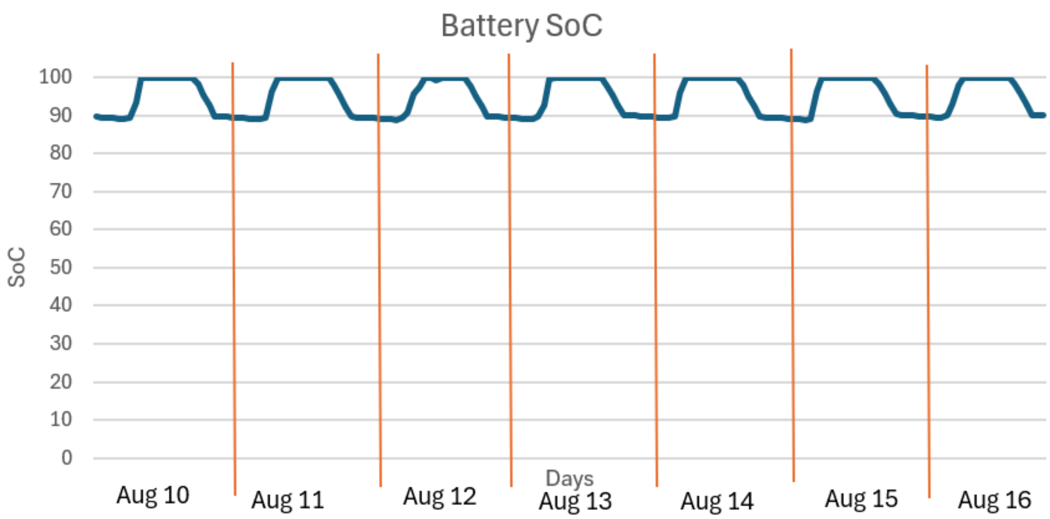

Figure 5. 11. August's SoC of the battery

- **Case 2:- Dry Season**

  By considering sample week (i.e. Feb 16-22), it can be observed that the generator operates around noon but it doesn't operate at other time of the day. The PV has supplied the daily load i.e. 6 AM to 6 PM. Whenever there is shortage, the battery and the generator fill the shortage.

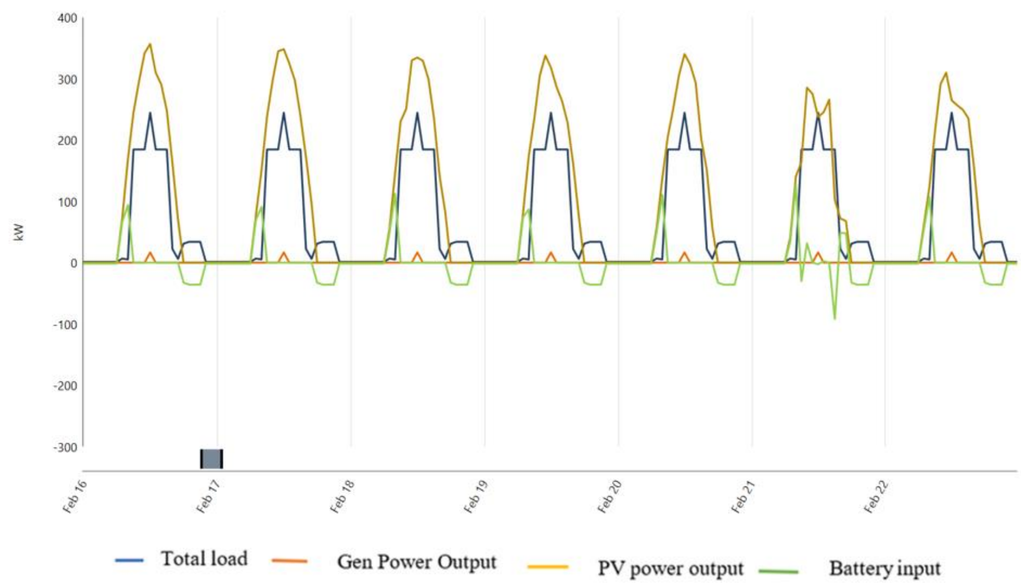

Figure 5. 12. Generation and Consumption of dry season (i.e. February 16-22)

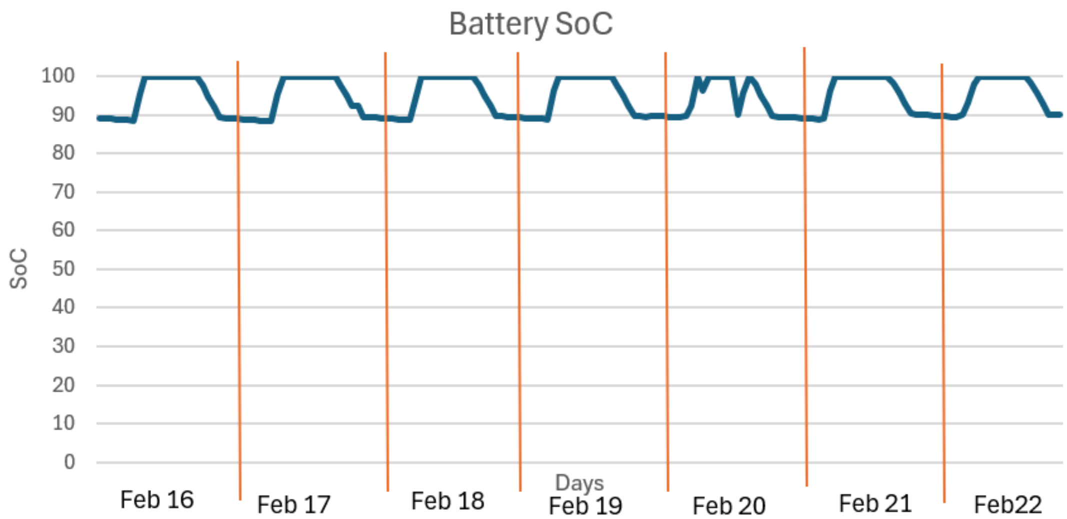

Figure 5. 13. Feburary's SoC of the battery

5.2. Sensitivity Analysis

Several optimization runs are carried out by using a distinct set of input assumptions for the sensitivity analysis. It helps the designer to understand the effect of the various inputs like solar irradiation, wind speed, fuel price on the NPC and LCOE of different schemes. The solar irradiation used for the sensitivity analysis 5, 5.5, 6.5 and 7 kWh/m^2/day. The wind speed used for the sensitivity analysis 2.5, 3, 3.5, 4 and 4.5 m/s. The diesel price used for the sensitivity analysis 1, 1.2, 1.5 and 1.6 $/lt.

In the figure below, the effect of the solar irradiation and fuel price on the NPC is shown at constant wind speed. The solar irradiation is plotted on the X-axis and the diesel price is plotted on the Y-axis. As the solar irradiation increases the NPC decreases and as the diesel fuel price increases the NPC increases. The highest solar irradiation and lowest fuel price result in the lowest NPC. When the solar radiation is 7kWh/m^2/day and when the fuel price is $1/litre, the lowest NPC is $ 446,725 obtained. The lowest solar irradiation and highest fuel price result in the highest NPC. When the solar radiation is 5 kWh/m2/day and when the fuel price is $1.6 /litre, the highest NPC is $ 543,503 obtained.

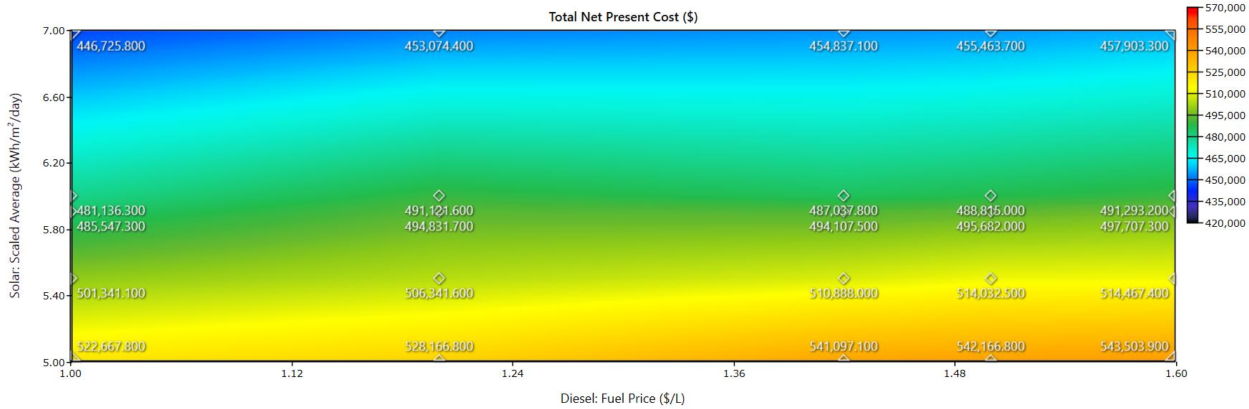

Figure 5. 14. Sensitivity analysis of total NPC

In the figure below, the effect of solar irradiation and fuel price on the COE is shown at constant wind speed. The solar irradiation is plotted on the X-axis and the diesel price is plotted on the Y-axis. As the solar irradiation increases the COE decreases and as the diesel fuel price increases the COE increases. The highest solar irradiation and the lowest fuel price result in the lowest COE. When the solar radiation is 7kWh/m^2/day and when the fuel price is $1/litre, the lowest COE is $ 0.080 obtained. The lowest solar irradiation and highest fuel price result in the highest COE. When the solar radiation is 5 kWh/m^2/day and when the fuel price is $1.6 /litre, the highest COE is $0.097/kWh obtained.

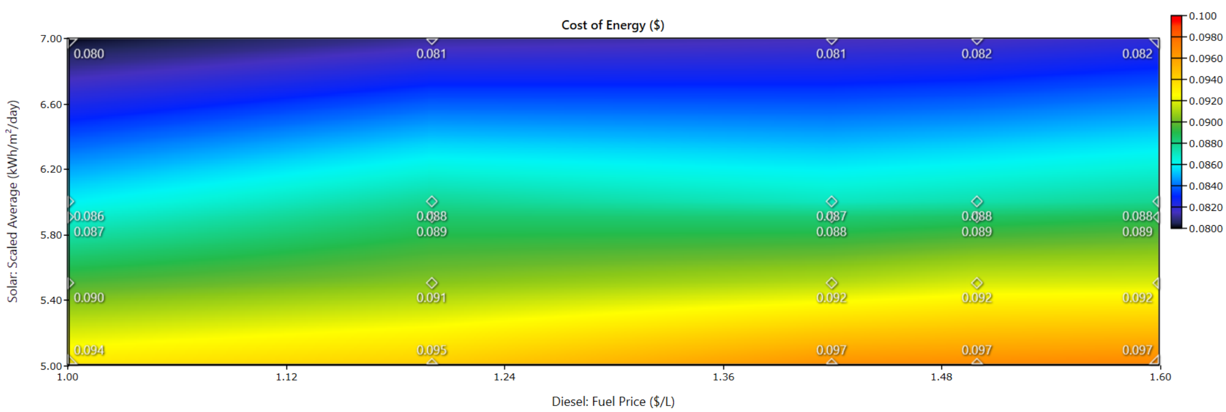

Figure 5. 15. Sensitivity analysis of total COE

5.3. Comparison between Diesel and Electric Expense for Irrigation

In order to identify the amount of money that farmers saved using the solar mini-grid technology proposed by the researcher and it utilized the energy cost only as a comparison parameter.

According to the analyzed data gathered from the questionnaire, the farmers needed 10 liters of diesel fuel to irrigate 1 hectare of land using diesel generators and they irrigate every three days, which means 10 times in a single month. The table below shows the diesel fuel expense to irrigate the farm in the kebele.

Table 5. 5. Annual Diesel Expense for irrigation

Description	Quantity
Diesel fuel consumption to irrigate one hectare	10 litre
Irrigation frequency per month	10 times
Monthly diesel consumption per one hectare	100 litre/month/hec
Total irrigation farm size of the kebele in hectares	50 hectare
Monthly diesel consumption for total farm	5,000 litre/month
Irrigation month in the year	8 month/year
Annual diesel requirement	40,000 litre/year
Diesel cost per litre	ETB 80/litre
Annual diesel cost in ETB	ETB 3,200,000/year
Exchange rate ETB to Dollar	USD 1= ETB 55
Annual diesel cost in USD	**USD 58,181.82**

If the farmers used the intended solar technology, the electricity cost for irrigation is shown table below.

Table 5. 6. Annual Electricity Expense for irrigation

Description	Quantity
Daily energy consumption of the pump	1,050 kWh/day
Monthly energy consumption of the pump	31,500 kWh/month
Irrigation month in the year	8 month/year
Yearly energy consumption of the pump	252,000 kWh/year
Cost of Energy	USD 0.0885/kWh
Annual Energy cost	**USD 22,302**

By comparing the two costs, using mini-grid electricity will bring **USD 35,879.82/year** savings for the farmers. If the proposed mini-grid solution is implemented the community will also benefit from the electricity and they can keep their environment.

The primary job in determining irrigation energy demand is determining crop water requirement. To this end, the study uses the CROPWAT 8.0 program to accurately estimate the amount of water required for the crops planted in the study area. This aids in the identification and sizing of irrigation energy demand.

The major load of the site is irrigation which is 67% of the loads. The optimization and sensitivity procedures were done by HOMER. There is flexibility in load management with irrigation load since it can vary from day to day or from one hour to the next. By permitting an annual capacity shortage, two scenarios are examined in this study. In this research, the effect of capacity shortage is examined. The capacity shortage allowed for simulation is 1% and 2%. The COE is minimized for the capacity shortage simulation. By comparing the fuel consumption and GHGs emition, the capacity shortage of 1% is selected which is scenario-1 as optimal solution. PV-Gen-Battery is recommended system based least NPC and COE. The COE of the selected system is small when it is compared to the COE of other researchers reviewed in the literature review. The transition of the irrigation from diesel irrigation to electricity has financial savings to the farmers.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

This study used HOMER software to do a techno-economic feasibility analysis of a mini-grid employing a hybrid renewable energy system for Shima kebele, a rural village in North Shoa, Ethiopia. The mini-grid is intended to provide power to households, business centers, government office, schools, churches, and irrigation systems. The irrigation system's water requirement was determined using the CROPWAT software and it accounts for 75% of the village's energy requirement. The research area's solar irradiance and wind speed were obtained from the NASA website.

For developing nations like Ethiopia, electrifying rural areas is and will continue to be a difficult task. Grid extension is expensive to electrify rural areas because the community are sparsely populated and far a way from the existing grid network itself. Because of high cost of transimistion and extremely low load factor in these areas, extentending the grid is not ecconimicaly feasible. Combining renewable energy sources with energy storage technology can provide sustainable solutions to the country's energy needs.

In addition to improving the countries education standards, lowering domestic pollution levels, and reducing the use of firewood for energy production, addressing the nation's electricity deficit would have a significant positive impact on rural communities' quality of life. Considering all of these factors, the higher expense shouldn't be justified. Therefore, increasing the use of additional renewable energy sources, such as solar and wind power systems, can alleviate the nation's electric deficit.

In this study, the energy required for irrigation was calculated based on the water requirement of the crop which depends on the nature of the soil, the weather conditions of the area, and the cropping season, reference evapotranspiration (ETo), irrigation water requirements (IR), rainfall and crop type. FAO developed the decision-support software application CROPWAT 8.0. Onion water requirement is 8.65 mm/day and Tomatoes water requirement is 11.04 mm/day, which is equivalent to 4,922.5 m^3/day required to irrigate 50 hectares.

Load management is flexible with irrigation load since it can change from day to day or from hour to hour. This study examined three possibilities based on an annual capacity shortage. The scenario with 1% annual capacity shortage, is selected because its lower fuel consumption. As the off-grid system is being designed, the simulation results are sorted according to the NPC of different configurations, listing them from top to bottom, 60 kW of generator power, 343 kW of solar PV and 922 kWh make up the lowest NPC system. The system's penetration rate for renewable energy is 96.6%. The lowest NPC obtained is USD 494,107 and USD 0.0885/kWh of COE.

The sensitivity analysis is also conducted, change in the solar irradiation and price of fuel have affected the NPC and COE of the system. The increase in solar irradiation and decrease fuel prices result in the lowest NPC, and decrease solar irradiation and increase fuel prices result in the highest NPC. It is also similar to COE. The financial benefit analysis for irrigation was also done. The electricity could save around $36,000 per annum when compared to diesel. The result of the study can help in encouraging the different stakeholders in investing in mini-grids to tackle socio-economic problems of the rural community.

6.2. Recommendation

The socio-economic of rural Ethiopia is affected due to lack electricity. Even though the government has invested a lot in this sector but it couldn’t able to succeed 100% electrification in the country. The involvement of private sector and development partners is crucial to achieve this target. Since Ethiopia has a huge potential of renewable energy resources (hydro, wind, solar, geothermal, and biomass) which can be utilized to achieve this goal and to provide affordable energy. This study recommend

- To determine the ideal sizing, three scenarios were assessed. Utilizing the annual capacity shortage allows the researcher to obtain optimal outcomes.
- Price flexibility for COE should be implemented. Tariffs for households should not be the same as those for business centers and irrigation systems.
- With an aggregated order, it is possible to obtain better unit prices for different components, minimizing project costs that have an impact on project costs.

- While mini-grids are developed or designed, it is to integrate with the productive use of energy. It will give sustainability for the mini-grid and the community's ability to pay.
- The COE can be reduced by obtaining grants from the donors for building the mini-grids which is common in the sector.

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ANNEX I

Appendix I: Questionnaires

Questionnaire for Households

A. Location and General Information

- ✓ Region: ____________Zone: _______________Woreda: ____________________
- ✓ Sex of respondent: Male ☐ Female ☐
- ✓ Occupation: ____
- ✓ Age of respondent: ____
- ✓ Position as a family member: _____________Total Number of family: ________

1. Numbers of rooms in the house.
   a. One ☐ b. Two ☐ c. Three ☐ d. > Three ☐
2. Numbers of mobiles phones in the house.
   a. One ☐ b. Two ☐ c. Three ☐ d. > Three ☐
3. Numbers of cattle's
   a. Two ☐ b. Three ☐ c. Four ☐ d. > Four ☐
4. Size of the farm land (in hectare)
   a. Below 1 ☐ b) 1-1.5 ☐ c) 1.5-.2 ☐ d. >2 ☐
5. Source of income
   a. Farming ☐ b) animal herding ☐ c) employed ☐ d) other ___________
6. Annual income in Birr
   a) Below 15,000 ☐ b) 15,000-20,000 ☐ c) 20,000-30,000 ☐
   d. 30,000-40,000 ☐ e) 40,000-50,000 ☐ f) More than 50,000 ☐
7. Monthly expense in Birr
   a. Below, 1000 ☐ b) 1,000-2,000 ☐ c) 2,000-4,000 ☐
   d. 4,000- 6,000 ☐ e) 6,000-10,000 ☐ f) >10,000 ☐

Questionnaire for irrigation

Location and General Information

- ✓ Region: ___________Zone: ______________Woreda: __________________
- ✓ Sex of respondent: Male ☐ Female ☐
- ✓ Occupation: ___________________ Age of respondent: ______________________

1. The size of farm only irrigated in hectare
   a. Below 2 b) 2- 5 c) 5--10 d) 10-20 e) Other _________
2. The irrigation farmland
   a. Owned ☐ b) Rented ☐ If the answer rented, how much _____________
3. Kind of horticulture cultivated with irrigation
   a. Onion ☐ b. Tomato ☐ c. Potato ☐ d. Avocado ☐
   e. Banana ☐ f. Orange ☐ g. Lemon ☐ h. Other ___________
4. Kind of cereals cultivated using irrigation
   a. Teff ☐ b. Maize ☐ c, Barely ☐ d. Sorghum ☐ e. other _________
5. How many time in a year you produce crops using irrigation
   a. 1 ☐ b) 2 ☐ c) 3 ☐ d) 4 ☐
6. Have you conduct crop rotation
   a. Yes ☐ b. No ☐
7. How much quintal harvested from one hectare for a specific crop _____________

About the water

8. Source of irrigation water
   a. River ☐ b. Lake ☐ c. Well ☐ d. Other_______
9. Type of Irrigation
   a. Surface irrigation ☐ b. Drip irrigation ☐ c. Sprinkler irrigation ☐
10. Availability of the water though out the year
    a. Available ☐ b. No Available ☐
    If the answer is no available, which month _______
11. Distance between the water sources to the farm land.
    a. 10-100m ☐ b. 100 -500m ☐ c. 500-1000m ☐ d) >1000m ☐
12. Is there sharing schedule of the water source?
    a. Yes ☐ b. No ☐
13. What is the frequency of irrigating?
    a. Everyday ☐ b. Every other day ☐ c. Two time in week ☐ d. weekly ☐
    e. other_____________

Diesel Pump questions

14. Ownership of the pump
    a. Owned ☐ b. Rented ☐ If pump is rented, how much ____________

15. Operating hours (hr/day)
    a. Below 2 hrs ☐ b. 2 - 4hrs ☐ c. Above 4 hrs ☐

16. Pump Specification
    ____

17. Estimated fuel consumption per hectare (in liter per day)
    a. Below 5 ☐ b. 5-10 ☐ c. Above 10 ☐

18. Where do you buy the fuel?
    a. Fuel station ☐ b. Shop ☐ c) Other________

19. Price of buying the fuel
    a. Diesel ____________ b. Petrol____________

20. Monthly fuel expense in birr
    a. Below 1500 ☐ b. 1500-2000 ☐ c. 2000-3000 ☐ d. >2300 ☐

21. Monthly maintenance cost in birr
    a. Below 500 ☐ b. 501-750 ☐ c. 751-1000 ☐ d. >1000 ☐

22. Time required to bring fuel to the field
    a. Below 1 hr. ☐ b. 1-2 hr. ☐ c. 2-3 hr. ☐ d) More than 3 hr. ☐

Questionnaire for business center, government institution and religious center

Location and General Information

- ✓ Region: ___________Zone: ______________Woreda: __________________
- ✓ Sex of respondent: Male ☐ Female ☐
- ✓ Age of respondent: ____
- ✓ Position: ____________

	Sector	Appliance	Number	Wattage	Hours of use
1.	School	Lamp			
		Desktop computer			
		Copy machine			

		Printer			
		Mobile charger			
2.	Business center	Lamp			
		Refrigerator			
		TV			
		Decoder			
		G PAS			
3.	Church	Lamp			
		Speaker			
4.	Shop (Milling)	Lamp			
		Mobile charger			
		Milling machine			
5.	Health center	Lamp			
		Desktop computer			
		Printer			
		Mobile charger			
		TV			
6.	Bar	Lamp			
		Stove			
		Mitad			
		Refrigerator			
7.	Kebele administration office	Lamp			
		Desktop computer			
		Copy machine			
		Printer			
		Mobile charger			

ANNEX II

Households

Low-Class Households (in W)

S/N	Appliance	Wattage	Qty	Total Wattage	Working Hour	Customer	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	2	26	4	459																			11934	11934	11934	11934		
2	Mobile charger	15	2	30	2	459										2295	2295	2295	2295	2295	2295				3443	3443	3443	3443		
3	Radio/Tape	20	1	20	4	459								2295	2295	2295	2295						4590	4590	4590	4590	4590	4590		

Middle Class Households (in W)

S/N	Appliance	Wattage	Qty	Total Wat	Working Hour	Customer	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	3	39	4	122																			6344	6344	6344	6344		
2	Mobile charger	15	3	45	2	122										915	915	915	915						915	915	915	915		
3	TV	70	1	70	4	122								2440												2440	2440	2440		
4	Cook Stove	1000	1	1000	1	122										20333	20333	20333	20333	20333	20333									

High Class Households (in W)

S/N	Appliance	Wattage	Qty	Total Watta	Working Hour	Customer	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	4	52	4	31																			1612	1612	1612	1612		
2	Mobile charger	15	4	60	2	31										232.5	232.5	232.5	232.5						232.5	232.5	232.5	232.5		
3	TV	70	1	70	4	31								620												620	620	620		
4	Cook Stove	1000	1	1000	1	31										5167	5167	5167	5167	5167	5167									
5	Refigrator	100	1	100	8	31	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3	1033.3
6	Injera	4000	1	4000	0.5	31													62000											

Health Center (in W)

S/N	Appliance	Wattage	Qty	Total Watt	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	10	130	4	39	39	39	39	39	39	39	39											39	39	39	39	26	26
2	Refrigerator	100	1	100	8	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33	33.33
3	Microscope	20	1	20	2											20					20								
4	Sterilizer	1000	1	1000	0.5									250						250									
5	Centrifuge	100	1	100	2											100					100								
6	Suction Pum	150	1	150	2											150					150								
7	TV	70	1	70	8									70	70	70	70		70	70	70	70							
8	Mobile Char	15	10	150	2								30	30	30	30	30	30		30	30	30	30						
9	Radio/Tape	20	2	40	4									40	40						40	40							
10	Printer	700	1	700	1									87.5	87.5	87.5	87.5		87.5	87.5	87.5	87.5							
11	Water Heate	1000	1	1000	1												500			500									

School (in W)

S/N	Appliance	Wattage	Qty	Total Watt	Working H	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	15	195	2	26	26	26	26	26	26	26	26											39	39	26	26	26	26
2	Mobile Charger	15	15	225	2									45	60	60	60		45	45	30	30	15	15	15	15	15		
3	Desktop computer	400	2	800	8									800	800	800	800		800	800	800	800							
4	Printer	700	1	700	1										175	175				175	175								
5	TV	70	1	70	2													70	70										
6	Radio/Tape	20	1	20	4									20		20		20			20								

Office (in W)

S/N	Appliance	Wattage	Qty	Total Watt	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	4	52	4	13	13	13	13	13	13	13												26	26	26	13	13	13
2	Mobile Charger	15	2	30	2									15	15	15	15		15	15	15	15							
3	Desktop computer	400	1	400	4										400	400				400	400								
4	Printer	700	1	700	1										175	175				175	175								

Shops (in W)

S/N	Appliance	Wattage	Qty	Total Wattage	Working Hour	Number	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	2	26	4	2																			52	52	52	52		
2	Mobile Charge	15	2	30	4	2									30	30	30	30		30	30	30	30							
3	TV	70	1	70	8	2															140	140	140	140	140	140	140	140		
4	Radio/Tape	20	1	20	10	2											40	40	40	40	40	40	40	40	40	40				
5	Refrigrator	100	1	100	8	2	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7

Mill (in W)

S/N	Appliance	Wattage	Qty	Total Wattage	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	3	39	4																			26	26	26	26		
2	Mobile Charge	15	2	30	4									15	15	15	15		15	15	15	15							
3	Mill	7500	2	15000	4											15000	15000				15000	15000							

Grocery and Restaurant (in W)

S/N	Appliance	Wattage	Qty	Total Wattage	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	5	65	6							65												65	65	65	65	65	
2	Mobile Charger	15	5	75	4									15	15	15	15		15	15	15	15		15	15				
3	TV	70	1	70	8															70	70	70	70	70	70	70	70		
4	LED light	50	1	50	4																			50	50	50	50		
5	Refrigrator	100	2	200	8	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7
6	G-pas	100	1	100	15								100	100	100	100	100	100	100	100	100	100	100	100	100	100	100		

Church (in W)

S/N	Appliance	Wattage	Qty	Total Wattage	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Light Lamps	13	15	195	4	65	65	65	65	65	65	65												52	52	52	52	52	65
2	Mobile Charger	15	2	30	2									15	15	15	15		15	15	15	15		15	15				
3	Sound system	100	1	100	4									100	100				100	100									

Irrigation (in W)

Qty	Total Wattage	Working Hour	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	273000	7										150000	150000	150000	150000	150000	150000	150000								

Total in kW

S/N	Description	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
1	Household	1.03	1.03	1.03	1.03	1.03	1.03	1.03	6.39	3.33	32.27	32.27	29.98	91.98	28.83	28.83	1.03	5.62	5.62	30.1	33.16	33.16	33.16	1.03	1.03
2	Health Center	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.1	0.51	0.26	0.49	0.72	0.06	0.19	0.97	0.53	0.26	0.06	0.07	0.07	0.07	0.07	0.06	0.06
3	School	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.87	1.04	1.06	0.86	0.09	0.92	1.02	1.03	0.83	0.02	0.05	0.05	0.04	0.04	0.03	0.03
4	Government offi	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
5	Shop	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.10	0.14	0.14	0.11	0.14	0.28	0.28	0.28	0.25	0.30	0.30	0.26	0.26	0.07	0.07
6	Mill	0	0	0	0	0	0	0	0	0.02	0.02	15.02	15.02	0.00	0.02	0.02	15.02	15.02	0.00	0.03	0.03	0.03	0.03	0	0
7	Grocery/Resturar	0.07	0.07	0.07	0.07	0.07	0.07	0.13	0.17	0.18	0.18	0.18	0.18	0.17	0.18	0.25	0.25	0.25	0.24	0.37	0.37	0.35	0.35	0.13	0.07
8	Church	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.00	0.12	0.12	0.02	0.02	0.00	0.12	0.12	0.02	0.02	0.00	0.07	0.07	0.05	0.05	0.05	0.07
9	Irrigation	0	0	0	0	0	0	0	0	0	150	150	150	150	150	150	150	0	0	0	0	0	0	0	0

ANNEX III

Site Pictures