Ethiopian Institute of Technology-Mekelle (EIT-M)
School of Mechanical and Industrial Engineering
Thermal and Energy Systems Chair

Feasibility Study of Integrated Hybrid Energy System for off-Grid Rural Electrification: Case of Three Village

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Mechanical Engineering

(Thermo fluid Engineering)

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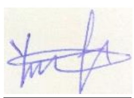
DECLARATION

I declare that this research entitled: - Feasibility Study of Integrated Hybrid Energy System for Off-grid Rural Electrification: Case of Three Villages “in the partial fulfillment of the requirement for the award of M.sc in mechanical and industrial engineering is an authentic record of my work, under the supervision of Ephrem Yohannes, mechanical and industrial engineering department, (EIT-M) Mekelle University, Mekelle Ethiopia. Others have not submitted the matter embodied in the thesis for the award of any other degree. All relevant information resources used in the thesis have been duly acknowledged.

Declared by: Ms. Yeshareg Yrgalem

Signature:  ________

Date: 01/08/2017

Advisor: Ephrem Yohannes Signature:  ____________________Date: 01/08/2017

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ABSTRACT

This research presents a feasibility study of an integrated hybrid energy system designed for off-grid rural electrification in three villages in Ethiopia's Tigray region. With over 56% of Ethiopia's population lacking access to electricity, the National Electrification Program (NEP) aims to achieve universal electricity access by 2025, promoting a mix of grid and off-grid solutions. This study explores the potential of combining wind, solar, and biogas to create a sustainable energy model that aligns with the NEP's objectives.

The objectives of this study are threefold: to assess the renewable energy resources available in the selected villages, to design and size the components of a hybrid energy system, and to evaluate the technical and economic feasibility of the proposed solution. The methodology involves data collection through site assessments, resource evaluations, load estimations, and modeling using the HOMER Pro software

The study evaluates the energy demands of Felege Mayat, May Shih, and Mayderhu villages, revealing daily energy requirements of 1673 kWh, 1215 kWh, and 785 kWh, respectively. The findings indicate that a hybrid system—combining wind, solar, and biogas—can deliver a sustainable, reliable, and cost-effective electricity supply, with levelized costs of electricity (COE) at $0.0139/kWh, $0.0158/kWh, and $0.0167/kWh for each village. This approach not only addresses the immediate energy needs in these rural communities but also promotes environmental sustainability by reducing dependence on traditional biomass.

In conclusion, this thesis highlights the potential of integrated hybrid energy systems to bridge the energy gap in rural Ethiopia, promoting sustainable development and improving human well-being. Recommendations for future research and implementation strategies are provided to facilitate the adoption of such systems in similar contexts.

Keywords: Hybrid Renewable Energy System, HOMER Software, Off-Grid Electrification, Sustainable Development, Ethiopia.

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LIST OF SYMBOLS AND ABBREVIATIONS FACTOR

Abbreviations	Description
HDI	Human Development Index
EE	Energy Efficiency
E*o*	Elevation [km]
P	Power[W]
PV	Photovoltaic
S	Second
T	Temperature
Tc	PV Cell Temperature [^{o}C]
Ta	Ambient Temperature [^{o}C]
W	Wind Speed [m/s]
Gsc	Solar Constant (0.0820) [MJ/m^2/day]
H	Solar Radiation [kWh/m^2/day]
Ho	Extra-terrestrial radiation [MJ/M^2/day]
I	Current [Ah]
MPPT	Maximum Peak Power Tracking
J	Joule
Kva	Kilovolt Ampere
KWh	Kilowatt-hour
Kw	Kilowatt
kWh/day.m2	Kilowatt hour per day square meter
M	Meter
N	Actual Duration of Sunshine [Hour]
DC	Direct Current
DOD	Depth of Discharge [%]
AC	Alternating Current
N	Daylight Hours [Hour]

V	Voltage
A	Rotor Swept Area [m^2]
Cp	Power Coefficient [%]
HOMER	Hybrid Optimization Model for Electric Renewable
LCOE	Levelized Cost of Energy [Birr/kWh]
NPC	Net Present Cost (Birr)
O&M	Operation and maintenance
E	Energy (kWh)
EEU	Ethiopian Electric Utility
EIM	Ethiopian Meteorological Institute
GREEK LETTERS	
α	Solar Absorptance of the PV Array [%]
δ	Declination Angle [◦]
η	Efficiency [%]
ϕ	Latitude of the Location [◦]
Ωs	Sunset Hour Angle [◦]
$P\alpha$	Density of Air [kg/m^3]

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CHAPTER ONE
INTRODUCTION

1.1 Background

All Sub-Saharan countries now have a total electrification rate for rural regions of just over 30% (World Bank, 2021). There are presently over 30 SSA countries with less than 50% electricity, 16 of which have less than 25%. Except in countries like South Africa, Ghana, Gabon, Cape Verde, Mauritius, Seychelles, and Gabon, where over 75% of the population has access to power, over 600 million people in the rest of SSA lack direct access to electricity. [1]

Sub-Saharan Africa (SSA) has an energy gap. Despite housing 16% of the world's population, the subcontinent only contributes 3% of the global electricity demand. Given the close relationship between development economic growth and energy availability.[2]

Sustainable Development Goal (SDG) number 7 (affordable and clean energy) recognizes as its first target, for universal, inexpensive, and reliable electricity access. Infrastructure facilitating access to electricity has positive and significant effects on several SDGs. According to the 2023 Tracking SDG7 Report, 660 million people—most of whom reside in Sub-Saharan Africa—would still not have access in 2030. [3]

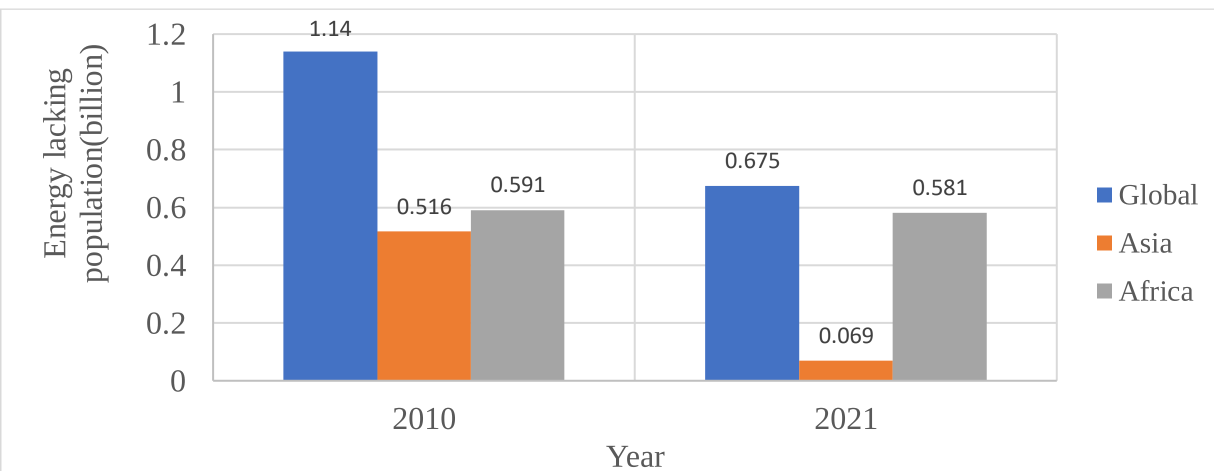


Figure 1. 1: Population without electricity

Ethiopia, one of the world's least developed nations, has poor energy access. Reportedly, less than 16% of the nation's population lives in places with less than 2% electrical availability, and 85% of people live there. This power shortage seriously hooks rural communities' socioeconomic development and quality of life. [4]

Ethiopia is a country rich in renewable energy resources, able to produce roughly 60,000 MW of electricity through the use of various renewable energy sources. Up to 45,000 MW of renewable energy can be produced through hydropower, 10,000 MW by wind, 5000 MW by geothermal energy, and 5.26 kWh per square meter per day can be produced through solar energy. This potential isn't being fully realized, though. Furthermore, the Ogaden Basin contains seven trillion cubic feet of natural gas reserves, as confirmed by the GOE in 2022. Less than 60% of Ethiopia's population is served by the 5,200 MW of installed power capacity currently in place. Although the GOE intends to raise power generation capacity to 17,000 MW in ten years, population expansion and ongoing economic development may cause demand for electricity to exceed supply. [5]

Hydropower accounts for around 90% of installed generation capacity; the remaining 10% is made up of thermal and wind sources (2% and 8%, respectively). Due to drought, the nation's present hydroelectric systems have produced less than their declared capability. The GOE is currently attempting to diversify the generation mix with additional sources like solar, wind, and geothermal energy to create a more climate-resilient power system. [6]

In the last 25 years, Ethiopia's rate of increase in electricity access has only been 30 percentage points, reaching 45% in 2018. When the 7% yearly growth rate from 2010 to 2018 is extrapolated, it would still take 19 years to reach universal access. In addition, the average annual usage of power is among the lowest in the world, with 83 kWh/capita in 2018 compared to the average of 500 kWh/capita for the African continent. In 2019, just 34% of rural households were linked to the grid. [7][8]

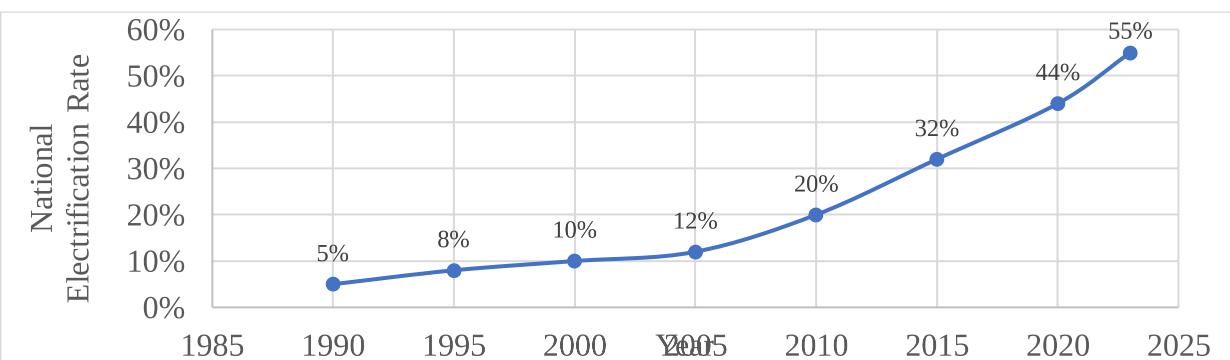


Figure 1. 2: Electrification growth of Ethiopia

Ethiopia's energy system has significantly impacted the ecology, which primarily relies on burning biomass. Particularly concerning is the fact that traditional fuels constitute the primary energy source for rural households, which make up the great majority of Ethiopia's population. These patterns of unsustainable fuel usage have led to deforestation, land degradation, lower agricultural output, and higher greenhouse gas emissions. These effects are made worse by Ethiopia's expanding population and its increased energy needs. [9]

The introduction outlines Ethiopia's electrical energy system's difficulties, such as the country's high energy demand, the effects of climate change, and energy scarcity. It notes that power outages and shadowing caused by low water levels in hydroelectric facilities are frequent occurrences even in the capital. The situation is terrible in rural areas where people rely on manual labor, firewood, and dry cells to supply their energy needs because they are remote from the main grid. [10]

The search for hybrid energy systems is driven by the rising need for clean and sustainable sources of power and the difficulties associated with expanding the grid to remote areas. A good solution can be a mini-grid hybrid system that combines several types of renewable energy sources to have an uninterrupted electricity supply. Also, renewable energy technologies have proven to be a promising solution to close the energy gap and promote sustainable development. [11]

The World Bank Group cites electricity as being essential to human development since it allows for greater leisure time, better health, and higher levels of education. Women and children spend hours of the day walking to gather fuel for cooking and lighting in regions like Ethiopia that rely on traditional fuels, leaving them with little opportunity to pursue other economic options. Additionally, burning wood pollutes indoor air, which harms health. [9]

The Human Development Index (HDI) is a composite indicator that reflects the overall well-being of a country by measuring three key dimensions: life expectancy (health), education, and per capita income (standard of living). The lack of electricity is directly linked to the low HDI in Ethiopia. It affects health, education, and economic activities, which are all essential for improving the living standards of the population.

From the HDI indicator, they provide data for Ethiopia from 2000 to 2021. The average is 0.407 points with a minimum of 0.283 points in 2000 and a maximum of 0.597 points in 2021. [12]

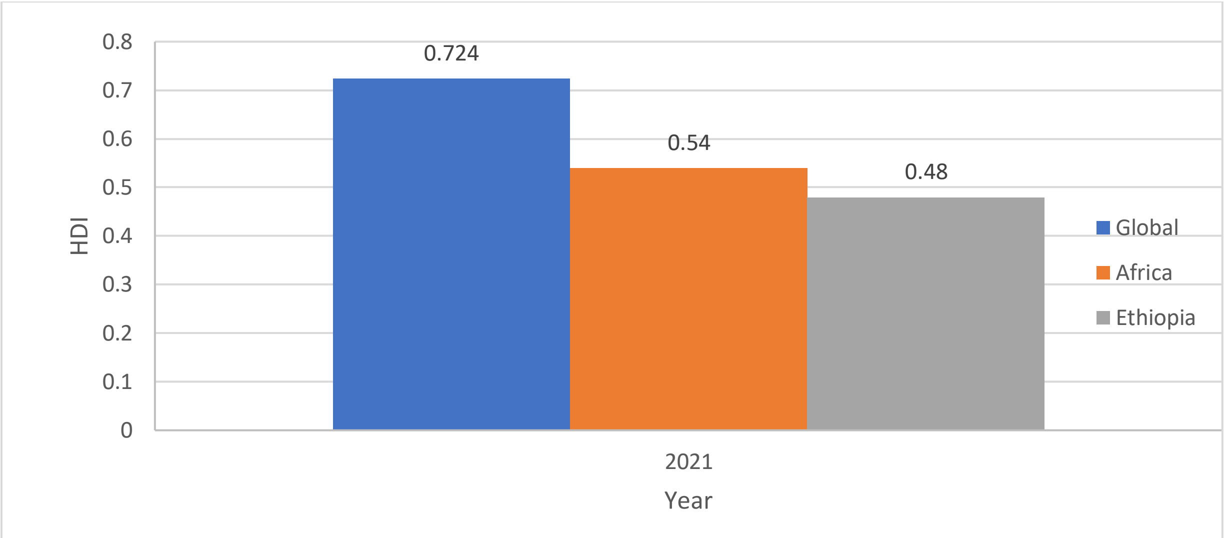


Figure 1. 3: Human Development Index

Policy and regulatory framework for renewable energy in Ethiopia

Almost 27% of rural homes have access to electricity services, compared to 96% of urban households (including 99.9% in Addis Ababa) that are linked to the grid. Off-grid options provide access for the majority of rural customers. The locations with the worst deficiencies are deep-rural areas, where just 5% of the population has access to electricity; these are followed by rural areas, where 5–10% of the population has access, and peri-urban areas, where 20% of the population has access. [13]

Three key national objectives can be achieved by addressing the access challenge through the coordinated deployment of all available technology options: (i) achieving a balance between efficiency and equity in the delivery of access; (ii) expanding the reach of the electrification program while reducing the amount of time needed for all Ethiopians to have access to electricity services; and (iii) promoting economic growth and human development. [13]

After the triumphant initiation and progressive execution of Ethiopia's First National Electrification Program (NEP) in 2017, the GoE has accomplished noteworthy benchmarks by linking 33% of its populace to on-grid electrification and 11% to off-grid pre-electrification, culminating in a collective attainment of 44% electricity access. The percentage of Ethiopians without access to power is still over half (56 percent).

Ethiopia's National Electrification Program (NEP 2.0) sets out the government's detailed action plan to electrify the country by 2025, as the nation also reforms major areas of its power sector. Under the NEP the government plans to provide 65% of its population with electricity via the national grid by 2025, and 35% via mini-grids and off-grid stand-alone systems. Between 2025 and 2030, the government plans to increase the population receiving grid electricity to 96%, with the most remote populations (4%) continuing with service from systems off-the-grid. [14] [15]

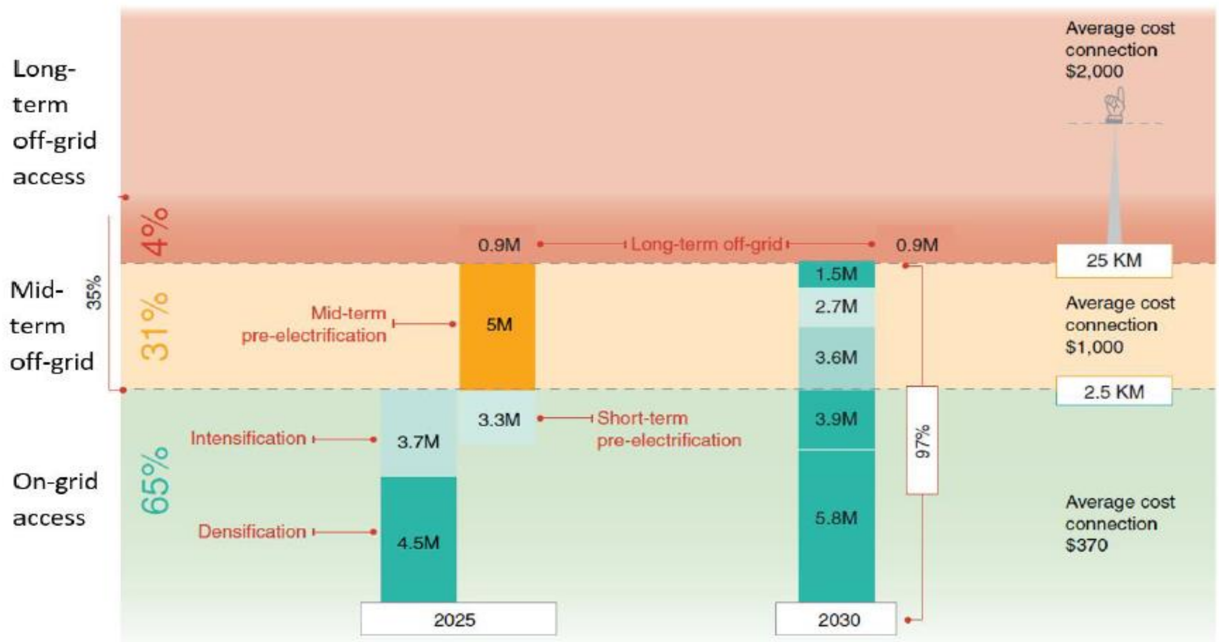


Figure 1. 4: Households to be electrified by NEP 2.0 [14]

The GOE has established Public-Private Partnerships (PPPs) for the transformation of energy project financing and implementation. Future geothermal, hydro, solar, and wind power generation projects will be developed by private Independent Power Producers (IPPs) utilizing project finance modalities, where the public sector will focus on regulatory and off-taker roles. The major gaps in transmission and substation development to supply industrial parks, railway lines, Agro-processing centers and rehabilitation of additional major towns are also being considered for Joint Venture development between the public and private sector. [13]

According to EEP's Corporate Planning Department, Ethiopia is set to increase installed power generation capacity to nearly 9000 megawatts by the end of the implementation period of the new strategic plan spanning 2023 to 2025. The power production stands at 4,820 megawatts from hydro, 404 megawatts from wind, and 25 megawatts from waste-to-energy. A key target is raising total grid-connected generation by 68% through projects currently underway. It is estimated some 3,600 additional megawatts will come online from the Grand Ethiopian Renaissance Dam, Asela Wind Farm, Aluto Langano Geothermal Plant, and Aisha Wind Farm – all scheduled for completion before 2025.[16]

Energy efficiency

Energy efficiency must be given top priority in every country or economic sector that wants to adopt sustainable development goals and optimize the benefits of using energy resources. A specific quantity of energy resources could enable additional national accomplishments. These include educating energy auditors for industrial end users and minimum efficiency standards. Operations are overseen by the Petroleum and Energy Authority (PEA), the regulatory body Include:

- Energy efficiency awareness campaigns
- Energy auditor and manager training
- Energy audits and voluntary agreements for the industry
- Lighting standards and labeling
- Efficiency labelling program
- Electric motor standards
- Injera mitad standards
- Electric cook stove standards
- Efficient Injera mitad manufacture
- Efficient welding systems.

There are prototype Injera mitad available that are said to consume 50% less electricity. They employ a redesigned design that is more energy-efficient (digital control), has superior insulation, and uses less peak power (1.6-2 kW as opposed to 3.5 to 4 kW). Some variants employ induction heating as an alternative to electric resistance heating. Overall, there are several strategies to maximize energy efficiency and reduce the amount of energy needed to create Injera. Additionally, mitad with digital control and reduced wattage (1600 W, 16" diameter) are available; these mitad claim to be more efficient than regular mitad. [17]

A significant obstacle to the promotion of energy-efficient appliances in Ethiopia is the country's vast informal market, where goods are exchanged without the buyer's ability to make decisions based on energy efficiency. Ethiopia does not make any of the domestic appliances, except the traditional Injera mitad.[17]

Structure of the thesis work

This thesis is organized into five chapters. **Chapter One** focuses on the background of the study. Particularly, it deals with the energy situation, energy potential in Ethiopia, and about hybrid system background. In addition, this chapter also explained the off-grid hybrid energy system, problem statement, objectives, scope of the study, significance of the study, and limitations. **Chapter two** covers the theoretical framework of the hybrid system, literature reviews related to the study of hybrid energy systems, and Homer Pro software tools. **Chapter three** covers the methodology that includes primary and secondary data collection, energy potential assessment of the sites, and load estimation. In this part, the selection of hybrid system Components and the design of the components are included. **Chapter four** deals with Hybrid system designing by Homer Pro software and presents results and a discussion of the output. Finally, **Chapter Five** presents the conclusions and recommendations of the thesis.

1.2 Problem Statement

1. Economic Disparities: Limited access to electricity restricts the potential for local businesses, agriculture, and entrepreneurship. The community cannot utilize modern agricultural techniques or technologies that could improve productivity and food security.
2. Environmental Issues: All of the households depend on traditional biomass fuels for cooking and other activities, leading to indoor air pollution that contributes to respiratory diseases and other health problems and it leads to environmental degradation, including deforestation.

3. Social Issues: Disparities in energy access contribute to social inequalities. Vulnerable populations, including most of the women and marginalized communities, often face barriers to obtaining reliable electricity, which limits their opportunities for education, healthcare, and economic participation.

4. Educational Challenges: Almost all of the students face different challenges regarding education by the Lack of electricity hinders access to educational resources, technology, and study opportunities, perpetuating cycles of poverty.

5. Legal Issues: Regulatory frameworks governing energy production, distribution, and consumption can be inadequate or overly complex, creating barriers to investment and implementation of electrification projects. Legal uncertainties may deter private sector involvement and hinder community-led initiatives.

1.3 Objective of the study

1.3.1 General Objective

The main objective of this research is to conduct a Feasibility Study of an Integrated Hybrid Energy System for off-grid Rural Electrification in the Case of Three Village.

1.3.2 Specific Objective

- To investigate resource assessment & energy consumption profile
- To design & size of components
- To perform a technical & economic visibility study
- To perform a sensitive analysis using Homer Pro

1.4 Scope of the study

- Site selection and assessment: Identify rural areas for implementing the integrated hybrid system, and evaluate the available renewable energy resources and their potential.
- Technical feasibility: Determine the optimal system size and configuration to meet the estimated electricity demand. Evaluate the system's performance, efficiency, and reliability under various operating conditions.
- Social and environmental impact: Evaluate the potential social benefits of the hybrid energy system and assess the environmental impact of the system, including the reduction in greenhouse gas emissions and the sustainable use of natural resources.
- Institutional and regulatory framework: Examine the existing institutional and regulatory environment governing rural electrification and renewable energy deployment.

1.5 Significance of the study

- To improve performance and minimize cost
- Enhanced Functionality: Hybrid systems often offer expanded functionality compared to their components.
- To have Flexibility and Adaptability Risk Mitigation and Redundancy
- Sustainability and Environmental Impact

1.6 Limitations of the study

- Data Availability and Reliability: The study relies on secondary data sources, which may have limitations in terms of accuracy and completeness. Inconsistent data on renewable energy resources could affect the feasibility assessment.
- Geographical Constraints: The study focuses on only three villages in the Tigray region, which may not be representative of other rural areas in Ethiopia. Variations in resource availability and energy needs in different locations may limit the generalizability of the findings.

- Technical Assumptions: The feasibility study depends on specific technical assumptions regarding the performance of hybrid energy systems. Variations in technology efficiency and reliability could influence the actual outcomes.
- Economic Factors: The economic analysis is based on current market conditions, which may change over time. Fluctuations in energy prices, and investment costs.
- Social Acceptance: The study does not account for potential social and cultural barriers to the adoption of renewable energy technologies. Community engagement and acceptance are crucial for successful implementation.
- Regulatory Framework: Changes in government policies or regulatory frameworks regarding energy access and renewable energy deployment may affect the feasibility of the proposed solutions.

CHAPTER -TWO

2.1 Renewable Energy Potentials in Ethiopia

2.1.1 Wind Energy

Wind energy can be transformed into electrical or mechanical energy using wind turbines. Wind turbines convert the kinetic energy of the wind into mechanical power. A generator can be used to convert mechanical power into electrical power. Wind power is one sustainable and green energy source. The energy of the wind comes from its motion. They are coupled to a hub and a low-speed shaft, so they spin in unison with the blades. A gearbox attached to a rotating low-speed shaft is coupled to a high-speed shaft on one side of the gearbox. The mechanical energy of the rotating blades is converted into electrical energy by the electrical generator that powers this high-speed shaft. [18]

The EEPCo has included wind energy in its master plan for the next 25 years, but Ethiopians are reluctant to embrace wind due to its unpredictability. The majority of wind machines in sub-Saharan Africa, particularly in landlocked nations, are used to pump water rather than produce electricity due to the region's widespread low wind speeds. Bekele (2009) found that this resource has a poor and inconsistent potential in their investigation. The study's findings indicate that while wind energy may be integrated with other systems, such as solar photovoltaics, diesel generators, and batteries to generate electricity, the potential may not be sufficient for standalone wind systems. The study measured wind potential from four specific sites in Ethiopia. [9]

The potential of wind energy has been restricted to water-pumping applications in recent decades. At the moment, wind energy needs to be used to generate power, mostly for grid-connected systems. Approximately 1035 GW of power might be generated from wind energy. Ethiopia intends to generate over 860MW by the year 2015 and has already begun implementing wind farms in various parts of the nation. In Adama, 95 km east of the capital Addis Ababa, a single wind farm was inaugurated in 2012 with a 51MW generation capacity. The other wind farm, known specifically as Ashegoda, is located in the northern region of Ethiopia, close to Mekelle, and has a 120 MW generation capacity. It is anticipated to be finished. [19]

2.1.2 Solar Energy

With the help of international development organizations, solar photovoltaic (PV) technology is being actively explored throughout sub-Saharan Africa. Solar PV has been widely promoted, but it has faced obstacles that have so far proven too great for the technology to overcome to achieve widespread success. Not only is solar PV limited to low-voltage appliance powering and lighting, but it is also quite costly to install, particularly for rural communities with limited resources. [9]

Ethiopia experiences between 5.5 and 6.5 kWh/m^2/day of solar insolation on average. The insolation varies throughout the year, with seasonal variations not as severe as in extreme cases. It varies from 4.55 kWh/m^2/day in July to a maximum of 5.55 kWh/m^2/day in February and March. Additionally, there are geographical variations, with the South-West region experiencing 4.25 kWh/m^2/day to the North region experiencing 6.25 kWh/m^2/day. Currently solar energy sources have been started to be exploited for different applications. At this time the government has set a plan to generate electricity from five solar PV projects with a total intended capacity of 135MW until the period of 2030. [19]

2.1.3 Biomass Energy Source

About 89.6% of the total energy consumption in Ethiopia is composed of traditional biomass fuels, with only 10.4% coming from modern energy sources. The biomass *is* mainly obtained from firewood, charcoal, cow dung, and crop residues that mostly depend on the surrounding forest resources and agricultural residues.[26]

The main substrate used by domestic bio digesters is cow manure. Since more than 77% of Ethiopia's rural households own cattle, they are qualified to have bio digesters installed. An integrated crop-livestock agricultural system is managed by rural households. The population of the city determines how much municipal solid garbage is produced. It is also one of Ethiopia's prospective bioenergy resources that has accumulated in the form of landfills in urban areas. Global trash generation is currently estimated to be 2.01 billion tons yearly, and by 2050, it is expected to increase to 3.4 billion tons annually. [27]

Biogas Production

The production of biogas through AD offers significant advantages over others due to less biomass sludge, successful in treating wet wastes of less than 40% dry matter, it is more effective pathogen removal. Due to these reasons, AD is preferable. [28]

An anaerobic bacterial decomposition process transforms biomasses, including animal and agricultural wastes, human wastes, and agricultural residues, into high-quality, environmentally safe fuel called biogas that can be utilized for domestic needs. Biogas has an ignition temperature between 650°C and 750°C, making it 20% lighter than air. Similar to LPG gas, it is a colorless, odorless gas that burns with a clear, blue flame. With a 20 $MJ/_{m^3}$calorific value, biogas finds numerous home uses, including fuel for internal combustion engines that have been converted, lighting, cooking, and electricity production. [29]

Basic Stages of Biogas Production

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

$CH_3COOH \rightarrow CH_4 \quad +CO_2$

Acetic acid Methane Carbon dioxide

$2CH_3CH_2OH \rightarrow CO_2 \quad +CH_4 \quad +2CH_3COOH$

Ethane Carbon dioxide Methane Acetic acid

$CO_2 \quad +4H_2 \quad \rightarrow CH_4 \quad +2H_2O$

Carbon dioxide Hydrogen Methane Water

The process described above demonstrates how many products, by-products, and intermediate products are created during anaerobic digestion before the ultimate methane is formed. The following stoichiometric equation can be used to illustrate the creation of methane.

$C_aH_bO_cN_d + \frac{(4a-b-2c+3d)}{4}H_2O \quad \rightarrow \frac{(4a+b-2c-3d)}{8}CH_4 + \frac{(4a-b-2c+3d)}{8}CO_2 + dNH_3$ [29]

Factors Affecting Biogas Production

1. C/N Ratio
2. Feedstock composition
3. Total solids (TS) and volatile solids (VS) content
4. PH and alkalinity

5. Temperature

6. Hydraulic retention time (HRT) and organic loading rate (OLR)

8. Nutrient balance [29]

HOMER Pro Software

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, the performance of a particular power system configuration for each hour of the year is modeled to determine its technical feasibility and life-cycle cost. In the optimization process, many different system configurations are simulated in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, multiple optimizations are performed under a range of input assumptions to judge the effects of uncertainty or changes in the model inputs.

2.2 Literature Review

Linta K. and Kamran L. the authors offer a hybrid system for the Balochistani coast that combines solar and wind power systems with inverters. They analyzed many scenarios and calculated the power generation, emissions, capital costs, and average power generation costs using HOMER Pro software. The suggested hybrid system design is the most advantageous in terms of running costs, net current costs, and gas emissions, according to the results, which are displayed graphically and tabulated. [30]

Nader B. and Pearl D. present the necessity of renewable energy sources is emphasized in this paper, particularly in rural locations without grid connectivity. It makes clear that there is a limited supply of fossil fuels, environmental issues exist, and clean, sustainable alternatives are required. The authors draw attention to the possibility of autonomous renewable energy systems for distant area electrification. These include fuel cell electrolyzes, batteries, diesel generators, hydropower, photovoltaics (solar), converters, and hydrogen tanks. [31]

Solomon Teklemichael presents research on evaluating an off-grid hybrid renewable energy system in Atsbi District, North Ethiopia. The study simulated and optimized an optimal system configuration consisting of 100 kW wind turbines, 150 kW photovoltaic array, 250 kW diesel generator, 400 kWh battery bank, and a 100-kW power converter. This system was designed to meet the primary load demand of 1,505 kWh/day and the deferrable load of 17 kWh/day. The results showed that this system can achieve a renewable energy fraction of 61%, with an excess electricity generation of 23% and a cost of energy of \$0.456 per kWh.[19]

Fikadu Kifle studies the design and optimization of a hybrid power generation system consisting of solar photovoltaic (PV), micro-hydro, and biomass sources for the Kedemesa Kebele region in Jimma Zone. The key output results include the determination of an optimal hybrid system configuration (250 kW solar PV, 100 kW micro-hydro, and 150 kW biomass gasifier), a diversified energy generation profile (45% solar PV, 35% micro-hydro, and 20% biomass), favorable economic feasibility (LCOE of \$0.156/kWh, NPV of \$2.4 million, and IRR of 15.7%), and significant environmental benefits (2,130 tons of annual CO2 emissions reduction). [32]

Feyisa Bekele researched an off-grid hybrid system consisting of micro-hydro, solar PV, diesel generator, and battery storage, which is the most feasible and cost-effective solution for electrifying the Melkey Hera village in western Ethiopia. The optimized system configuration includes a 20 kW micro-hydro turbine, 13.8 kW solar PV array, 15 kW diesel generator, and 78 kWh battery bank. This hybrid system can meet the estimated electrical demand of the village, which is around 75 kWh/day, with a high degree of reliability. The levelized cost of energy (COE) for this system is estimated to be \$0.233/kWh, which is lower compared to the alternative of grid extension.[33]

M.B. Kahsay, F.Y. Hagos's paper presents a comprehensive wind energy resource assessment of the Geba catchment in northern Ethiopia, providing valuable insights into the wind characteristics of the region. The key findings show that the catchment has good wind power potential, with average wind speeds ranging from 3.7 m/s to 6.64 m/s and mean power densities from 64 W/m^2 to 301 W/m^2 at 10m above ground level. The wind resource map developed using WAsP indicates mean wind speeds of around 6.5 m/s and power densities of around 288 W/m^2 at 50m above ground level, highlighting the suitability of the area for wind energy development. [34]

Wondwosen S. Aga and Ayele N. present a document on a case study on the hybridization of green energy sources, specifically solar, wind, and diesel generators, for the electrification of the remote village of Adem Tuleman in Ethiopia. The results indicate that the proposed hybrid system is a feasible and climate-smart solution to electrify the remote village, with an average daily energy demand of 204.04 kWh, a peak load of 31 kW, and a deferrable load of 4.5 kWh. The financial analysis shows an initial capital cost of $24,817, an operating and maintenance cost of $12,862, and a total net present value of $189,233, with a minimum cost of energy of $0.195/kWh. [35]

Deepak K., Bibhuti B. The researchers go over energy storage, different renewable and alternative energy sources, and how well they work in terms of price and efficiency. To research and create the suggested model for a hybrid alternative energy system, they employ the software HOMER, which stands for Hybrid Optimization Model for Electric Renewable. A sensitivity analysis carried out using the HOMER tool is included in the study. The authors conclude that alternative and renewable energy sources can eventually take the place of traditional energy sources and offer a workable solution for the distribution of electrical energy in far-off places.[36]

Getachew B. and Gelma B. The research they study is made to provide a model village in a distant area with the need for energy. This entails supplying energy for infirmary medical supplies, water pumps, radio reception, grain mills, and lights. The authors were able to compile and evaluate a list of electricity demands by doing simulations in HOMER. (The net cost is used to arrange the supply systems. The most economical setup for the supplied was found with the use of this information.[10]

Getachew B. and Getnet T. They study the Feasibility study of a small Hydro/PV/Wind hybrid system for off-grid rural electrification in Ethiopia. They took into account the community's need for electrical energy, which included grain mills, water pumps, radios, televisions, lights, and electric bakeries. Health stations and elementary schools were also considered. For system optimization and sensitivity analysis, the researchers employed the HOMER (Hybrid Optimization Model for Electric Renewable) program. Based on their analysis, they determined various system types and component sizes that would lead to energy prices below $0.16/kWh, and they chose the Taba (B) location for a thorough investigation.[4]

Getu Tadesse researched the Feasibility Study and Design of Solar PV-biomass Hybrid Power Generation Systems. The project aims to provide the best possible system configuration for the selected site based on hourly energy availability and demand data by integrating solar, biomass, and energy storage. It draws attention to the advantages of combining biomass and solar energy to generate electricity, such as the ability to store energy in smaller batteries. Due to its availability throughout the day and at night, biomass energy can make up for the lack of solar energy during the night. For 190 HHs the NPC cost is $1,222,595, the operating cost is $29,147 and the COE is 0.069$/kWh.[37]

Alfa Hailemariam, Mulu Bayray study on Hybrid Solar – Wind – Diesel Systems for Rural Application in North Ethiopia for Three Rural Villages using HOMER Simulation. Ethiopia's potential for renewable energy is highlighted in the publication, which also contains a study of the literature on the evaluation of Ethiopia's solar and wind energy resources. Ethiopia is noted for having a high potential for solar and wind energy, particularly in its northern regions, which makes hybrid solar wind systems with diesel backups a viable choice for off-grid power delivery.[38]

Research presents a techno-economic feasibility analysis off-grid hybrid renewable energy system for rural electrification in a village in Balochistan, Pakistan. The proposed system integrates wind turbines, solar PV modules, and battery storage to meet the primary electric load demand of 197.74 kWh/day with a peak load of 27.87 kW. The study used HOMER-Pro software to model and optimize the hybrid system configuration, which consists of 12 kW wind turbines, 103 kW solar PV, 224 lead-acid batteries, and 29.1 kW converters. The simulation results show that the optimized hybrid system configuration has a Net Present Cost (NPC) of $127,345 and a Cost of Energy (COE) of $0.137/kWh, with a 100% renewable energy fraction. [39]

The study presents a comprehensive techno-economic analysis of an off-grid hybrid power system for a remote village in Ladakh, India. The proposed PV/wind/battery/diesel generator hybrid system was found to be the most feasible solution, with a net present cost of $278,176 and a levelized cost of energy of $0.29/kWh. The hybrid system achieved a 95.97% reduction in carbon dioxide emissions compared to a diesel-only system. The analysis also evaluated the impact of economic parameters on the system's net present cost and cost of energy. [40]

The study presents a thorough technical and economic analysis of a hybrid solar, wind, and energy storage system for a university campus. The simulation results indicate that the optimal system configuration includes a 3007 kW PV array, two 1.5 MW wind turbines, and a 1927 kW converter. This hybrid system is shown to have a Net Present Cost (NPC) of $6.58 million and a Cost of Energy (COE) of $0.132/kWh, which are 40.8% lower than the current grid-based electricity costs. The findings can be useful for policymakers and campus administrators looking to implement similar carbon-neutral energy systems in regions with comparable climatic conditions. [41]

The research paper evaluates the technical and economic feasibility of a hybrid renewable energy system combining diesel, PV, and wind for an off-grid location. Using HOMER Pro software, the study finds that the proposed PV-Wind-Diesel hybrid system is the most cost-effective solution, with a levelized cost of energy of $0.2424/kWh. The optimization approach and hybrid system design perform well in meeting the electrical demand, demonstrating the benefits of combining multiple renewable technologies over relying solely on conventional or renewable sources to achieve an optimal, cost-effective, and sustainable energy solution for the off-grid setting. [42]

This article provides an in-depth analysis of hybrid power systems (HPS) and their applications globally, with a focus on solutions relevant to Saudi Arabia. The author examines the most commonly used HPS configurations, including wind/solar-PV, wind/solar-PV/diesel, and solar-PV/diesel systems, both with and without battery storage. The review highlights the popularity, with the wind/solar-PV, wind/solar-PV/diesel, and solar-PV/diesel systems accounting for 28%, 22%, and 21% respectively. The average costs of energy (COE) for these HPS are around $0.458/kWh, $0.355/kWh, and $0.349/kWh, respectively. [43]

The study employs the Hybrid Optimization Model for Electric Renewable (HOMER) software to determine the optimal configuration of a solar PV-battery system, which emerged as the most cost-effective solution with a Net Present Cost (NPC) of $18,161 and a Cost of Energy (COE) of $0.233/kWh. The authors also conducted a sensitivity analysis to investigate the impact of key parameters like wind speed, solar radiation, and discount rate on the NPC and COE. The results demonstrate the significant potential of renewable energy sources, particularly solar PV, to address the electricity access challenges in rural Nigeria. [44]

The research article presents a comprehensive techno-economic analysis for the optimal sizing of an off-grid hybrid renewable energy system to provide electricity to a rural community in Sri Lanka. The authors have considered a rural village with a daily electricity demand of 270 kWh and a peak of 25 kW, evaluating the combination of wind turbines, photovoltaic, battery storage, and a diesel generator as the optimal hybrid system configuration. Their analysis shows that this system can supply electricity at an approximate levelized cost of $0.3/kWh, with the energy cost remaining stable even with variations in the annual average wind speed and solar irradiation. [45]

Based on the techno-economic analysis and optimization results presented in the paper, the proposed hybrid wind-solar-diesel with battery storage system appears to generate significant value compared to a diesel-only system for the off-grid power station in Dongwangsha, China. The simulation results indicate that the hybrid system achieves a substantially lower net present cost (NPC) of $1,401,765 compared to $2,131,741 for the diesel-only system. Additionally, the levelized cost of energy (COE) for the hybrid system is $0.215/kWh, which is significantly lower than the $0.327/kWh for the diesel-only option. [46]

The research paper's in-depth analysis of seven microgrid scenarios for Kutubdia Island highlights the economic advantages of the PV/Wind/Diesel/Converter/Battery configuration. This scenario demonstrates the lowest net present cost (NPC) of $8.40 million and the lowest cost of energy (COE) at $0.212/kWh among the evaluated options. In comparison, the PV/Wind/Converter/Battery scenario, the second-best performer, has a slightly higher NPC of $8.47 million and a COE of $0.214/kWh. The superior economic performance of the PV/Wind/Diesel/Converter/Battery scenario, as evidenced by its lower NPC and COE, makes it a highly attractive choice. [47]

The research paper presents a detailed feasibility analysis of a 100MW photovoltaic (PV) solar power plant in Rajshahi, Bangladesh, using the RET Screen software. The power generation cost is estimated at $0.09/kWh, the annual power generation is projected to be 140,155 MWh, and the project is expected to reduce greenhouse gas emissions by 78,797.7 tCO2 per year. The financial analysis, including net present value and cumulative cash flow calculations, further supports the project's feasibility. The researchers conclude that the 100MW PV solar power plant is a suitable option for Bangladesh to meet its goals of expanding clean and sustainable energy sources. [48]

2.3 Case Study of the Areas

Enderta is located on the eastern edge of the Tigray highlands and administration is one of the districts of the southeastern zone of Tigray Regional State, North Ethiopia. This paper aims to design an off-grid hybrid renewable energy system for the electrification of three villages Tabia Felege Mayat (**13° 36.8' N** latitude and **39° 29.5 ' E** longitude an elevation of **2401**m) the village has around 650 households, May Shih village (**13° 66' N** latitude and **39° 29.5 ' E** longitude an elevation of **2401**m) in this area the number of households is around 462, and Mayderhu village

(**13° 36.8' N** latitude and **39° 29.5 ' E** longitude an elevation of **2401**m) the number of the households is around 308 which are found in Enderta, southeastern Tigray. The living condition of the people in this area depends upon agriculture. The villagers in this area use kerosene for lighting, firewood, cow dung, agricultural residues for all household activities, and primary cells for radio and music players.

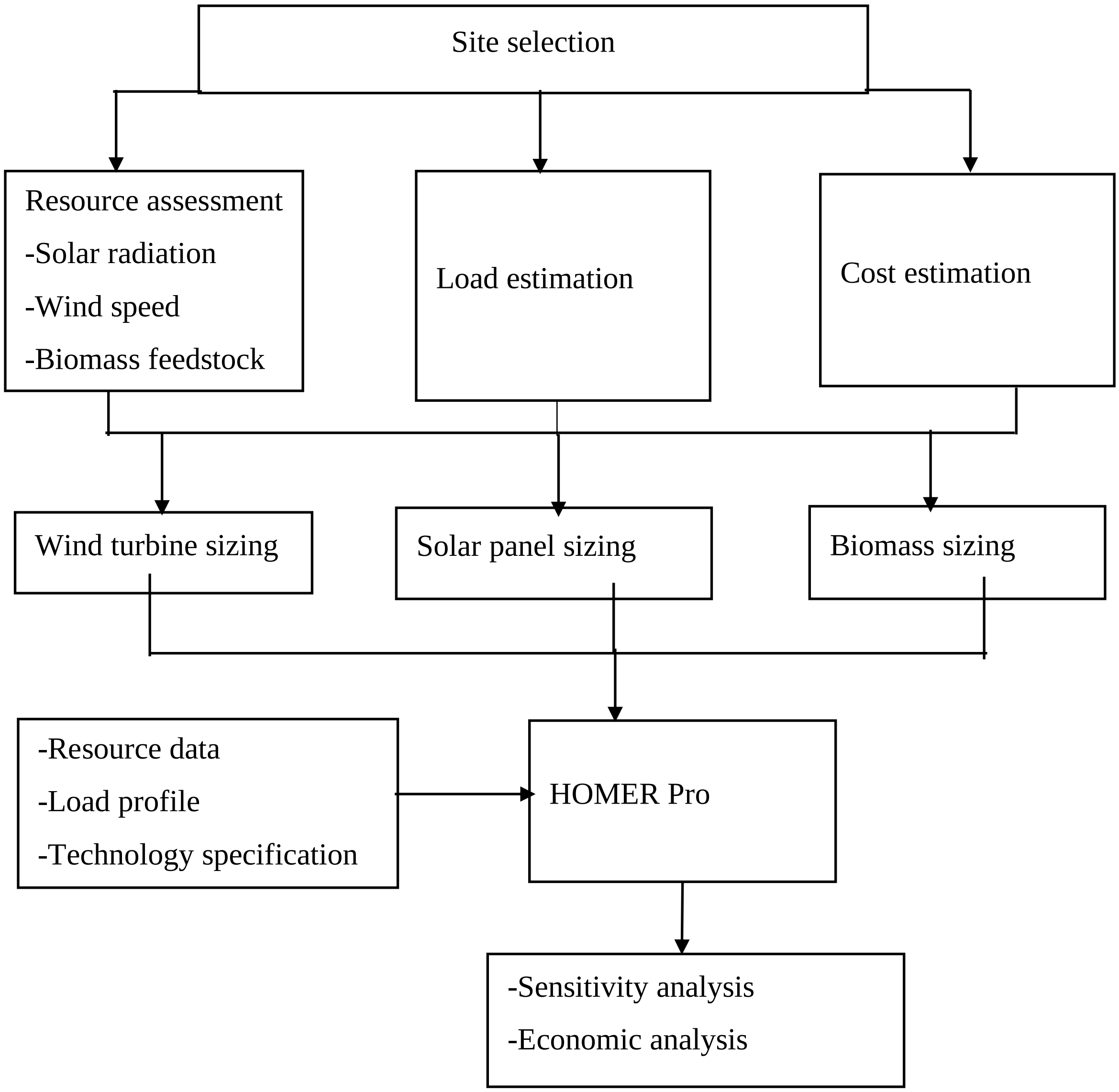
Figure 2. 1: Map of Felege Mayat

Figure 2. 2: Map of May Shih

Figure 2. 3: Map of Mayderhu

CHAPTER THREE

3. Methodology



3.1 Data collection

Sources of data for this study are classified into two. These are primary data sources and secondary data sources. These sources of data are discussed in the following ways.

Primary Data Collection

Primary data are the data collected through field surveys at the sites. The community services and commercial loads are collected from the village district, and the local people live near the selected area. The demand load of each village is analyzed by conducting interviews with the community by providing questionnaires.

Secondary Data Collection

Secondary data is data, which is obtained from other related literature. The most common solar energy resource data which is the average daily sunshine hour's data is collected from the National Meteorological Agency of Ethiopia (Mekelle branch) which is used to estimate the solar-radiation energy of the sites.

3.2 Resource Assessment of the Sites

The most common solar energy resource data collected in many of the meteorological stations (NMSA) throughout the country is the average daily sunshine hours. The available sunshine hour data from the National Meteorological Agency of Ethiopia (Mekelle branch) was used to estimate the solar-radiation energy of the sites.

Modeling Daily Solar Radiation

For the first station, 7 years, and for the second station 15 years, the average sunshine hour data available has been converted to monthly average daily global solar radiation the detailed data are found in the Appendix (Table A.2). The Angstrom estimation, the model was used to find the monthly average daily global solar radiation by using input data such as latitude, the average day in the month, the declination angle for the day, and the sunshine hour data. A worksheet was created with all the input data for each month and employing Eq. (3.1). The parameters N, a, n, b, H_o and finally, H was calculated. [23][49][50]

$$H = H_o\left(a + b\left(\frac{n}{N}\right)\right) \tag{3.1}$$

Whereas

H = is the monthly average daily global solar radiation

H_o= is monthly average daily extraterrestrial solar radiation

a and b are Angstrom's correlation parameter

$\frac{n}{N}$ = relative sunshine duration

n = is the monthly average daily hours of sunshine from the sunshine recorder

N= is the monthly average of the maximum possible hours of sunshine

Maximum possible daily sunshine duration (daylight hours) can be expressed by

$$N = \frac{24}{\pi}\ \omega_s \tag{3.2}$$

Where:

ω_s Is the sunset hour angle [rad]

$$\omega_s = cos^{-1}(-tan\varphi\ tan\delta) \tag{3.3}$$

Whereas,

φ Latitude [rad] and

δ Solar declination angle [rad]

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365}J\right) \tag{3.4}$$

$$\delta = 0.409\ sin\left(\frac{2\pi}{365}J - 1.39\right) \tag{3.5}$$

Where, J – is the number of days between 1 (1 January) and 365, or 366 (31 December).

Extraterrestrial radiation H_o [MJ/m^2/day] is expressed by the equation

$$H_o = \frac{24(60)}{\pi} G_{sc} d_r[\omega_s sin\varphi\ sin\delta + cos\varphi\ cos\delta \sin\omega_s] \tag{3.6}$$

Where:

H_o is extraterrestrial radiation [MJ/m^2/day]

G_{sc} Is solar constant = 0.0820 [MJ/m^2/day]

d_r Is inverse relative distance Earth-Sun

ω_s Is the sunset hour angle [rad]

φ Latitude [rad] and δ solar declination angle [rad]

Using the above formulas, the solar declination maximum possible duration of sunshine or daylight hours, average daily extraterrestrial radiation, and average daily solar radiation on the horizontal plane are calculated by Excel spreadsheet.

Table 3. 1 Solar potential of the sites from different resources

Site	Global solar atlas	Angstrom	Literature
Felege Mayat	6.254	5.3	-
May Shih	6.172	5.3	5.6
Mayderhu	6.137	5.7	5.6

Wind and Biomass Energy Potential of Felege Mayat

Previous research done by Dr. Mulu Bayray made wind mapping for Messobo so the site I selected is almost 5km far from Messobo. I take the wind potential from the literature that measured wind speed at 30m height is 5.71 $m/_s$ [34] .

Wind and Biomass Energy Potential of May Shih

The village is near Hagereselam, which is 5km from the Wereda. Previous research done by Dr. Mulu Bayray made wind and solar mapping on Hagereselam Wereda so the site I selected is almost 6 km far from the Wereda I used the potential of solar and wind from that research the measured wind speed at 30m height is 7.7 $m/_s$ .The total daily average solar radiation for the site was 5.6 $kWh/m^2/day$ [34] and the village has around 1386 cattle.

Wind and Biomass Energy Potential of Mayderhu

Previous research done by Dr. Mulu Bayray made wind mapping and solar mapping on this village (Mayderhu) so I can use the potential of solar and wind from that research the measured wind speed at 30m height is 6.03$m/_s$. The total daily average solar radiation for the site was 5.6 kWh/m2 /day from previous work [34], Mayderhu Village has around 924 cattle for the hybrid system.

Table 3. 2: Wind & Biomass potential of the sites

Site	Global wind ATLAS	Literature	Biomass
Felege Mayat	6.1 m/s	5.7 m/s	15,600 kg/day
May Shih	7.06 m/s	6.96 m/s	11,088 kg/day
Mayderhu	6.22 m/s	6.03 m/s	7392 kg/day

3.3 Load Estimation for the Sites

The hybrid system in the village is needed to supply reliable and uninterrupted electricity to the off-grid community. In Felege Mayat village there are 650 households with different income levels depending on the energy usage and their economic level they are divided into two classes which are 75% of the society have low income and the remaining 25% have high income.

In May Shih village there are 462 households which has different income levels. Depending on the HHs' energy usage I divided them into two classes which are 75% of the society has low income and the remaining 25% has a high income.

For the third village Mayderhu I made the load estimation of 308 households with 70% HHs having low income and the remaining 30% HHs having high income.

Table 3. 3: Load estimation of the villages

No	Appliance	Felege Mayat	May Shih	Mayderhu
1	Lamps	107	76	50.65
2	Mobile charger	58.5	41.6	27.7
3	Radio	248.7	176.8	113.4
4	Television	97	69	55.8
5	Injera mitad	231	163.8	132.5
6	Milling machine	400.64	300.64	200.64
7	Health center	11.2	10.25	9.725
8	School	1.558	1.408	1.198
	Total	1155	839	592

The detailed analysis of the load estimation for each village is found in the Appendix (A.3-A.12)

Power and Population Projection of the Villages Calculating power and population projection is important in this case to reduce load variability and future energy increases. Load forecast was done by taking the population growth of the community living in the village.

Table 3. 4 Population number of the sites

Year	Numbers of HHs			Total Population		
	Felege Mayat	May Shih	Mayderhu	Felege Mayat	May Shih	Mayderhu
2016	650	462	308	3600	2944	1968

Since the population census didn't last almost 9 years so I take the population growth rate of Ethiopia.

To estimate the number of populations I use the below equation [51].

$$P_n = P_o(1+r)^n \tag{3.7}$$

P_n= population at time n in the feature

P_o= present population

R =annual growth rate of population

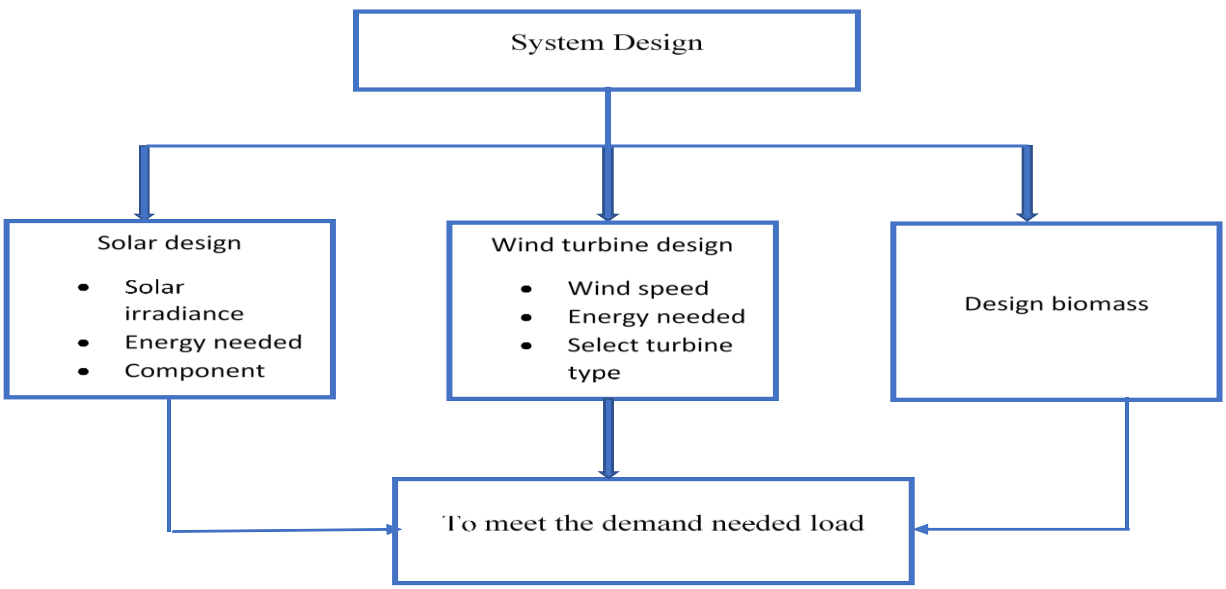
N = Year of projection

The population growth calculated for 15 years is found in the Appendix (Table A.1).

Table 3. 5 Total power needed after population projection

Calculated	Felege Mayat	May Shih	Mayderhu
Growth rate	2.5%	2.5%	2.5%
Number of populations after 15 years	5214	4264	2850
Power for projected population	518 $\frac{kWh}{day}$	376 $\frac{kWh}{day}$	265 $\frac{kWh}{day}$
Total required power	1673 $\frac{kWh}{day}$	1215 $\frac{kWh}{day}$	785 $\frac{kWh}{day}$

3.4 Design of Components



3.4.1 Design of Solar Panel

Formulas for the design of solar panel

$$Daily\ system\ charge = \frac{Total\ energy\ demand}{System\ Voltage} \tag{3.8}$$

System designed to charge current

$$\frac{\textbf{Daily system charge requirement}}{\textbf{Solar insolation}} \quad (3.9)$$

Effective PV cell Temperature

$$T_{cell,eff} = T_{amb,site} + 25 \quad (3.10)$$

An MPPT (Maximum Peak Power Tracking) controller will be used; the temperature derating factor is

$$f_{temp} = 1 - \gamma\left(T_{cell,eff} - T_{stc}\right) \quad (3.11)$$

Whereas

T_{stc}= is the temp under standard test conditions (25℃)

$$P_{mod} = P_{stc} * f_t * f_{man} * f_d \quad (3.12)$$

Whereas

P_{mod} = is the derated power output of the PV module using charge controller (w)

P_{stc} = is the nominal module power under standard test condition (w)

f_{man}= the derating factor for manufacturing tolerance, dimensionless

f_{dirt} = is the derating factor for dirt/soiling (for clean = 1.0, for high=0.92 medium = 0.97, for low 0 .98)

Sizing the PV Array

The number of PV modules required for the PV array

$$\mathrm{N} = \frac{E_d * f_o}{P_{mod} * \eta_{pv} * G} \quad (3.13)$$

Whereas

E_d = is the designed total energy (kWh)

f_o= is the assumption of the oversupply coefficient (PV)

G = is the worst solar insolation value at the Felege Mayat site location

η_{pv}= is the efficiency of the PV subsystem

Calculate the number of modules in a parallel

$$N_{ms} = \frac{System\ Voltage}{Nominal\ Voltage} \quad (3.14)$$

$$N_{ps} = \frac{Total\ number\ of\ modules\ for\ system}{Numbers\ of\ modules\ in\ a\ string} \quad (3.15)$$

Design the Area Solar Panels

$$A_p = \frac{Daily\ energy\ demand}{G} \quad (3.16)$$

Battery sizing

The battery type selected is a Li-ion LFP system, which is Iron Edison LFP1400Ah-48v, they are known for their high energy density, long cycle life, and packs more energy per unit weight and volume. It needs a nominal capacity of around 1400Ah.

$$\text{Battery load } (B_l) = \frac{Average\ daily\ energy\ utilization}{Battery\ voltage} \tag{3.17}$$

Battery Ampere hour (Total battery capacity) [22]

$$\frac{number\ of\ days\ of\ autonomy * B_l}{Depth\ of\ discharge * \eta} \tag{3.18}$$

Number of batteries

$$N_b = \frac{Total\ battery\ capacity}{Battery\ capacity\ of\ each} \tag{3.19}$$

Sizing and specifying of charge controller

The solar charge controller needs to have enough capacity to handle the current from the PV array. According to standard practice, the sizing of the solar charge controller is to take the short circuit current (I_{sc}). [23][24]

$$\text{Controller size} = N_{ps} * 1.2 * I_{sc} \tag{3.20}$$

Whereas

The safety factor is 1.2 when the sun's radiation exceeds nominal radiation.

Sizing of Inverter

An inverter is used in systems that require AC power output. The total power consumption of the appliances must consistently surpass the inverter's input rating. Both the battery's and the inverter's nominal voltages must coincide. For a standalone system, the inverter must be large enough to handle all of the watts used simultaneously. It is advised to use an inverter that is 25% to 30% bigger than the overall wattage of the equipment. [25][20]

3.4.2 Design of Wind Turbine

Formulas for the design of wind turbine

Air density

Air density varies with the variation linearly with the atmospheric pressure, temperature, and elevation. The higher the altitude the less dense the air, thus the air density is the function of pressure and temperature and is explained by the gas law as follows. [20]

$$\rho = \frac{P_{atm}}{RT} \tag{3.21}$$

If pressure and temperature data is not available, the correlation formula in eq. (2.2) may be used for estimating the air density. [21][20]

$$\rho = \rho_{o-1.194*10^{-4}*H_m} \tag{3.22}$$

Swept Area

The wind turbine's power output also depends on the turbine's rotor-swept area. The swept area of HAWT is determined as follows.

$$A = \frac{\pi D^2}{4} \tag{3.23}$$

A larger blade length or rotor diameter results in a larger swept area and wind turbines with a larger swept area generate more electrical energy.

The theoretical wind power is defined as [20]

$$P_{T=\frac{1}{2}\rho*A*V^3} \tag{3.24}$$

$$Actual\ P_\rho = Ideal\ P_\rho * loss\ factory \tag{3.25}$$

The value of C_p depends on the ratio of the downstream to the upper stream wind speed. The graph of C_p versus Vo/V indicates that the C_p max value is 0.59 when $\frac{V_o}{V}$ is one-third (1/3). Thus, the theoretical maximum value of C_p is 0.59, whereas the value of C_p for practical design is below 0.5 for high-speed wind turbines.

$$Annual\ P_\rho = Actual\ P_\rho * hours\ per\ year \tag{3.26}$$

$$Real\ annual\ P_\rho = Annual\ \ P_\rho * capacity\ factory \tag{3.27}$$

$$A_R = {}^{\text{Annual energy}}/_{119.4} \tag{3.28}$$

$$A_R\ = \pi R^2 \tag{3.29}$$

$$P_T = \ Actual\ P_\rho *\ A_R \tag{3.30}$$

$$No.of\ turbine = {}^{Daily\ energy}/_{Power\ rated} \tag{3.31}$$

3.4.3 Design of Biomass Energy

Design of each component of biomass energy

Daily Biogas Generation

$$G_d = VS\ Loading\ rate \times Biogas\ Yield \tag{3.32}$$

Dry matter (D_m) of fresh discharge

$$D_m = TS_d * \text{TS} \quad (3.33)$$

The volume of daily discharge of substrate is

$$V_s = \frac{m_{slurry}}{\rho_{slurry}} \quad (3.34)$$

The volume of the digester is,

$$V_d = V_s * \text{RT} \quad (3.35)$$

Since the biogas will be stored in a pressure vessel outside the digester, the volume required for the digester can be as small as possible. Therefore, the digester volume is:

$$V_d = V_d - G_d \quad (3.36)$$

Choosing a Fixed Dome Plant Type

Part of the digester below the ground level is subjected to heavy compressive load due to the earth pressure, which increases with depth. In this design due to hydrostatic pressure cylindrical digester was selected.

- Simplicity and Durability
- Cost-effectiveness
- Adaptability to Cow Dung
- Reliability and Longevity
- Biogas Storage
- Suitability for Small-Scale Applications

The Design Calculation and Dimension Relations

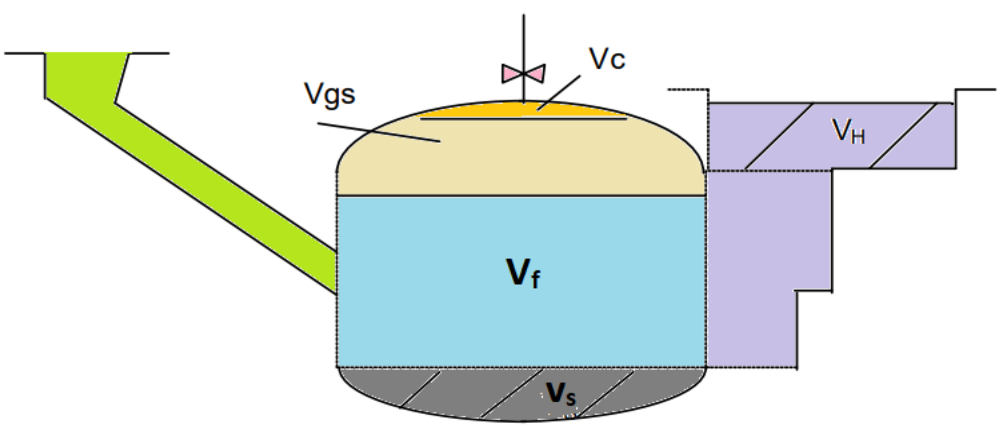


Figure 3. 1: Cross-section of a Digester [23]

Whereas

V_c= The volume of the gas-collecting chamber, V_{gs}= the volume of the gas storage chamber

V_f= The volume of the fermentation chamber, V_h= the volume of the hydraulic chamber

V_s= Volume of the sludge layer

The total volume of digester:

V=$V_c + V_{gs} + V_f + V_s$

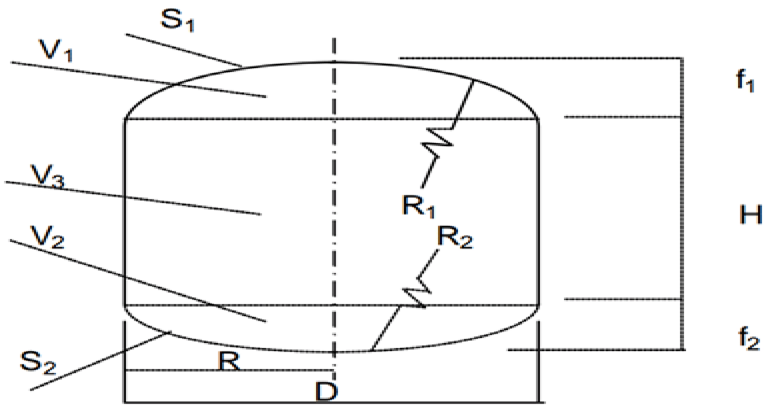


Figure 3. 2: Geometrical dimensions of the cylindrical-shaped biogas digester

Whereas,

V_1= Volume of gasholder

V_2= Volume of the sludge layer

V_3= Volume of fermentation

S_1= The surface area of the top dome

S_2= The surface area of the bottom dome

D=Diameter of the cylinder

Table 3. 6: Volume and Geometrical dimensions

Volume	Geometrical dimensions
$V_c \leq 5\%V$	D=1.3078 * $V^{1/3}$
$V_s \leq 15\%V$	V_1=0.0827* D^3
$V_{gs} + V_f = 80\%V$	V_2= 0.05011 *D^3
$V_{gs} = V_h$	V_3= 0.3142 *D^3
Where k=gas production rate per m^3 digester volume per day k=0.4	R_1= 0.725 *D

R_2= 1.0625 *D

$f_1 = \frac{D}{5}$

$f_2 = \frac{D}{8}$

The Working Biogas Digester Volume

$$W_v = V_{gs} + V_f \quad (3.37)$$

From geometrical assumptions: I have

V_{gs}+ V_f= 80% V

Pressure Developed in the Digester

The pressure of a gas mixture is equal to the sum of the pressure each gas would exert if it existed alone at the mixture temperature & volume. Dalton's law

$$P_m = \sum_i^k P_i\left(T_{m,V_m}\right) \quad (3.38)$$

The partial pressure of a gas is the pressure exerted by a particular component of a mixture of gases. It is given by

$$P_i V_i = n_i RT \quad (3.39)$$

Whereas,

P_i= The pressure developed by each gas of the mixture

V_i= The volume of a particular component of gas

T = Temperature of mixture in Kelvin

R =Ideal gas constant, n = number of moles of component

Based on the maximum volume of biogas produced per day it is possible to find the maximum gas pressure developed in the digester dome. 81 m^3 Biogas can be produced per day.

Table 3. 7: Composition of biogas

Substance	Symbol	Percentage
Methane	CH_4	50-60
Carbon Dioxide	CO_2	30-40
Hydrogen	H_2	5-10
Nitrogen	N_2	1-2

Water vapor	H_2O	0.3
Hydrogen Sulphate	H_2S	Traces

$$V_{gas} = \%Gas * G_d \tag{3.40}$$

Table 3. 8: Densities, molecular weight, and of gases (20 °C and 1atm)

Gas	Molecular Weight ($^g/_{mole}$)	Density ($^{kg}/_{m^3}$)
Carbon dioxide	44.01	1.98
Methane	16.04	0.667
Air(dry)	28.96	1.293
Hydrogen	2.015	0.0837
Nitrogen	28.014	1.2
Water Vapor	18.015	0.756
Hydrogen Sulfide	34.082	1.36

The below formula calculates the mass of the composition of biogas

$$m_{gas} = Density_{gas} * V_{gas} \tag{3.41}$$

The number of mole calculation of the Composition of biogas

$$Mole = \frac{mass}{Molecularweight} \tag{3.42}$$

The biogas saturates with water vapor and now the total pressure inside the digester is the sum of two pressures the dry gases and the water vapor.

Table 3. 9: Water vapor pressure at a specific temperature [23]

Temp (°C)	Vapor Pressure (mmHg)	Temp (°C)	Vapor Pressure (mmHg)
-10	2.15	40	55.3
0	4.58	60	149.4
5	6.54	80	355.1
10	9.21	95	634
11	9.84	96	658
12	10.52	97	682
13	11.23	98	707

14	11.99	99	733
15	12.79	100	760
20	17.54	101	788
25	23.76	110	1074.6
30	31.8	120	1489
37	47.07	200	11659

Partial Pressure for Each Gas in Biogas

If the number of particles in moles is given or desired, use the most common form of the ideal gas equation.

$$PV = nRT \tag{3.43}$$

The partial pressure of the gases:

$$P_{gas} = \frac{n_{gas} RT_{system}}{V_{system}} \tag{3.44}$$

Pressure Drop inside the Gas Pipes

Controlling the gas pressure system is necessary when designing a gas distribution system. Conventional biogas facilities provide biogas at a gauge pressure of roughly 981 Pascal. However, for optimal utilization in burners and lamps, it must be supplied at the site of application at a pressure of at least 785–981 Pascal. There is loss as the gas passes through a pipe because of the friction effect. Therefore, a properly built pipeline is one that, under no circumstances, causes a pressure drop of greater than 196–294 Pascal. The gas is regarded as an incompressible fluid to calculate the appropriate pipeline size because its density barely changes as it flows.

$$Q = VA \tag{3.45}$$

Whereas,

Q = Discharge (m^3/s)

V = Gas velocity (m/s)

A = Cross-sectional area (m^2)

The pressure drop of the gas is computed using Bernoulli's equation

$$\frac{P}{\rho g} + \frac{V^2}{zg} + Z = \text{constant} \tag{3.46}$$

Whereas,

P= Biogas pressure ($^{N}/_{m^2}$),

ρ = Biogas density ($^{kg}/_{m^3}$),

V = Biogas velocity ($^{m}/_{s}$),

g = Acceleration due to gravity (9.81$^{m}/_{s^2}$) and

z = Head (m)

In essence, Bernoulli's theorem says that in an ideal gas flow, the flow's velocity-related kinetic energy plus the pressure-related potential energy is both constant. In real life, Bernoulli's theorem needs to be adjusted when gas is passing through a pipe. To account for energy lost as a result of pipe friction, an additional term needs to be added:

$$\frac{P}{\rho g} + \frac{V^2}{zg} + Z + h_f = \text{constant} \tag{3.47}$$

Whereas,

h_f= head loss due to friction

Head Loss in Biogas Plant

The head loss in a pipe circuit falls into two categories:

A) due to viscous resistance extending throughout the total length of the circuit

B) Due to localized effects such as valves, sudden changes in area of flow, and bends. The overall head loss is a combination of both these categories.

The head loss due to friction in pipes

$$h_f = \frac{fLV^2}{2gd} \tag{3.48}$$

Whereas,

h_f= head loss due to friction

f = Friction factor depending upon the surface of the pipe (dimensionless)

L =Length of the pipe in meters

V =Velocity of gas

d =Diameter of pipe

- Friction factor for pipe: The value of friction, for smooth pipes, may be obtained by using the following expression:

  i. For laminar flow (R_e< 2300)

$$f = \frac{64}{R_e} \tag{3.49}$$

ii. For turbulent flow (R_e> 2300)

$$f = \frac{0.3164}{{R_e}^{0.25}} \tag{3.50}$$

Whereas,

$$R_e = \frac{VD}{\gamma} \tag{3.51}$$

V = Velocity of gas

D = Diameter of pipe

γ = kinematic viscosity

Head loss due to Bends

$$h_{m,b} = \frac{K_{bV^2}}{2g} * n_{elbow} \tag{3.52}$$

Whereas,

K_b= a dimensionless coefficient that depends on the bend radius/pipe radius ratio and the angle of the bend.

Head loss due to valves

The expression gives the head loss due to a valve

$$h_{m,v} = \frac{K_{vV^2}}{2g} * n_{valve} \tag{3.53}$$

K_v= The loss coefficient depends upon the type of valve and degrees of opening

Table 3. 10: Typical valves of loss coefficients for gate and globe valves [23]

Valve type	$\boldsymbol{K_v}$
Globe valve, fully open	10
Gate valve, fully open	0.2
Gate valve, half open	5.6

Head loss due to sudden changes in the area of flow

1. Sudden Expansion**:** In this design, there is no sudden expansion of the pipe. Since the main gas pipe is divided into the appliance gas pipe.

2. Sudden contraction - The head loss at a sudden contraction is given by

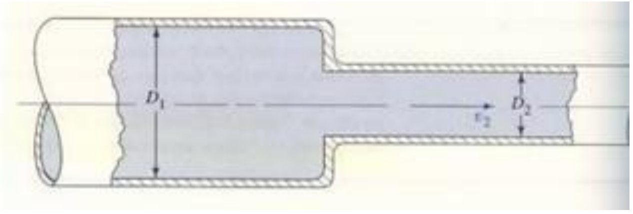


Figure 3. 3: Sudden contractions [23]

$$h_{m,c} = \frac{K{V_2}^2}{2g} \tag{3.54}$$

Whereas,

K= loss coefficient

Table 3. 11: Loss Coefficient for Sudden Contractions [23]

$\frac{A_2}{A_1}$	0	0.1	0.2	0.3	0.4	0.6	0.8	1.10
K	0.50	0.46	0.41	0.36	0.30	0.18	0.06	0

From the continuity equation:

$$A_1V_1 = A_2V_2 \tag{3.55}$$

Total pressure loss in pipes

$$P_{f,total} = \frac{\rho f L V^2}{2d} = \rho g h_{f,total} \tag{3.56}$$

Compression of biogas digester plant

Large biogas systems rely on compression to reduce the gas storage facility's size or transport the biogas to a pipeline. The choice of a blower or compressor depends on the pressure increase needed. To determine what type of compressor system is needed to accomplish the job, a variety of detailed data is needed to be discerned. As a minimum, a precise understanding of the following data is required:

- Gas being handled
- Flow rate
- Suction and discharge pressure
- Site elevation (or local barometric pressure)
- Suction temperature
- Capacity

Calculating Compression ratio

Compression ratio (R) is the ratio of discharge pressure to suction pressure:

$$R = \frac{P_d}{P_s} \quad (3.57)$$

- A single-stage compressor has only a single R-value.
- A two-stage compressor has three R values.

  R = Total compression ratio for the compressor

  R_1= Compression ratio for the first stage

  R_1= Compression ratio for the second stage

$R = \frac{P_d}{P_s}$,$R_1 = \frac{P_i}{P_s}$, $R_2 = \frac{P_d}{P_i}$

Whereas

P_s= Suction pressure

P_d=Discharge pressure

P_i= Inter-stage pressure- the pressure between $1^{st}$and 2^{nd} stage of the compressor.

Choosing one stage or two stage Compressor

The proper number of compression stages is largely based on the compression ratio. Here are some guidelines for choosing the proper number of stages.

Table 3. 12: Compression ratio vs. Proper number of Stages [23]

R-value	No. of stage
1-3	Single stage
3-5	Single-stage, occasionally two stages
5-7	Two-stage, occasionally single-stage
7-10	Two stages
10-15	Usually two stages, occasionally three-stage
15+	Three stages

Energy density and storage volume of plant

As biogas is compressed to higher pressures, its mass is pushed into smaller volumes. This raises the energy density of the gas and reduces the required storage volume. Note that the energy densities are much higher for biogas that has theH_2S, $CO_{2,}$ and water vapor removed (100% methane). The higher the compression ratio, the costs associated with compressing biogas will increase. For adiabatic compression, with no heat transfer across the system boundary (Q = 0), the thermodynamic relation is given by [23]

$$P_1 {V_1}^k = P_2 {V_2}^k \tag{3.58}$$

Whereas

k = Adiabatic rate $k = \frac{C_P}{C_V}$ = 1.3 for biogas

V_1= The initial volume of biogas that the plant produces per day.

P_2= Compressed raw biogas pressure

V_2= Compressed volume

P_1= total, partial pressure of biogas

Step 2: Density ρ of CH_4 in the mixture at actual pressure P and temperature T, calculated based on the table values at standard conditions

Temperature correction:

$$\rho_2 = \rho_1 * \frac{T_1}{T_2} \tag{3.59}$$

Pressure correction

$$\rho_2 = \rho_1 * \frac{P_1}{P_2} \tag{3.60}$$

$$\rho_{CH_4,act.} = \rho_{CH_4,std.} * \frac{P_{act}}{P_{std}} * \frac{T_{std}}{T_{act}} \tag{3.61}$$

Step 3: the actual calorific value of the given biogas

$$H_{u,act} = \rho_{CH_4,act.} * \frac{V_{CH_4}}{V_{tot}} * H_{u,n.} \tag{3.62}$$

Biogas emerging from the plant is usually fully saturated with water vapor, i.e., a relative humidity of 100%. Depending on the course of the gas piping between the plant and the consumer, part of the water vapor will condense when the gas is cooled. The humidity can be reduced by cooling and warming again of the gas with a drain trap for the condensate at the cooler. The gas analysis often does not consider the humidity or is done at the plant, not the consumer. In those cases, the moisture must be considered to establish the calorific value. This can be done by subtraction of the partial pressure of the water vapor from the total gas pressureP_t. The remainder is the corrected pressure value P_c to be considered in the above calculations of the calorific value.

$$P_c = P_t - p' \tag{3.63}$$

The partial pressure of water vapor is a function of the gas temperature and the relative humidity as given below.

Manufacturer's engine specification:

- power rating P = 20 kW
- fuel consumption at rated power fc = 10 $m^3n/_h$
- biogas used 70% CH_4, 30% CO_2

Specification of biogas

$H_{u,act}$=18,650 $kJ/_{m^3}$

- The calorific value of biogas used in the specification of the manufacturer:

$H_{u,act}$ = 25,000 kJ/m^{3}n (at standard conditions)

- Energy consumption (flow) of the engine at rated power

$$E = f_c * H_{u,act} \tag{3.64}$$

Stoichiometric air/fuel ratio

On a mass basis at the combustion of CH_4 with air is complete but without unutilized excess air

$\frac{m_{CH_4}}{m_{air}}$=

Properties of Biogas as Fuel for Internal Combustion Engine

Biogas is the product of fermentation of human and animal' biological activity waste products when bacteria degrade biological material in the absence of oxygen, in a process known as anaerobic digestion. Since biogas is a mixture of methane (also known as marsh gas or natural gas) and carbon dioxide is a renewable fuel produced from waste treatment Biogas contains 50% to 70% ofCH_4, 2 % of H_2 and up to 30 % of CO_2 . After being cleaned of carbon dioxide, this gas becomes a fairly homogeneous fuel containing up to 80 % methane with a calorific capacity of over 25$^{MJ}/_{m^3}$. The most important component of biogas, from the calorific point of view, is Methane, CH_4. The other components are not involved in the combustion process and rather absorb energy from the combustion ofCH_4, as they leave the process at a higher temperature than the one, they had before the process. Requirements to remove gaseous components depending on the biogas utilization.

CHAPTER FOUR

Result and Discussion

4.1 Numerical results

A. **Design steps of a solar panel for Felege Mayat village**

50% of the energy will be (0.5x 1673kWh /day) = 836.5kWh/day

Assuming a 20% System loss

= 1004 kWh/day

For the solar system, I select 48V the bigger the size the better for space saving using a big battery size with 48 volts instead of 12V, 24 V is better for avoiding the complexity of the system due to the large number of batteries. Having one big-size battery can solve the problem of cable losses used for the interconnection of the components.

Calculating the required daily system charge requirements from eq. (3.8)

=21 $^{kAh}/_{day}$

Solar insolation at the Felege Mayat site during July is = 4 kWh/m^2/day

Calculating the system-designed charge current from eq. (3.9)

= 5.25A

PV module with a 635 W N-type Mono-crystalline solar panel is selected for this project design.

Table 4. 1: Electrical Properties of Solar Panel

Nominal Power (P_{max})	635 W
Voltage Maximum Power (V_{mp})	47.46 V
Current Maximum Power (I_{mp})	13.38 A
Open Circuit Voltage (V_{oc})	56.85 V
Short Circuit Current (I_{sc})	14.04 A
Temperature coefficient of P_{max}	0.29%/℃
Module Efficiency (η)	22.8 %

1. Estimating the output of a single PV module

Peak power module 635 watt

Peak power temperature coefficient (ɤ=0.0029℃)

Manufacturing power output tolerance (3%)

The average daytime ambient temperature in the Felege Mayat site is 27℃, and the **effective PV cell Temperature** from eq. (3.10)

=27 +25= 52℃

The temperature derating factor from eq. (3.11)

f_{temp}= 1 −0.0029 (52 −25) = 0.92

From eq. (3.12)

f_{dirt} = is the derating factor for dirt/soiling (for clean = 1.0, for high=0.92 medium = 0.97, for low 0 .98)

P_{mod} = (635x0.92x0.97x0.97) w = 550w

The number of PV modules required for the PV array from eq. (3.13)

N = 590 modules

f_o= is the assumption of oversupply coefficient (PV) = 1.1

G = is the worst solar insolation value at the Felege Mayat site location = 4

η_{pv}= is the efficiency of the PV subsystem = 85%

Calculate the number of modules in parallel from eq. (3.14)

$= \frac{48v}{47.46}$=1.01

$N_{ps} = \frac{590}{1.01}$ = 584

Design the Area Solar Panels by using eq. (3.16)

= 251 m^2

Battery sizing

The battery type selected is a Li-ion LFP system, which is Iron Edison LFP1400Ah-48v, they are known for their high energy density, long cycle life, and packs more energy per unit weight and volume. It needs a nominal capacity of around 1400Ah.

Calculate battery load using eq. (3.17)

B_l = 35 kAh

Calculate Total battery capacity using eq. (3.18)

=$\frac{3*21}{0.8*0.95}$ = 138kAh

Calculate the number of batteries in series.

In this case, ${}^{48V}/_{48V}$ = 1 battery in series.

Calculate the number of batteries in parallel using eq. (3.19)

$N_b = \frac{138kAh}{1400Ah} = 98$

The final configuration of the complete battery system would be 1 battery in series, with 48 of these 48V 1400Ah battery strings connected in parallel. This would provide a 48V, 66kAh battery bank.

Sizing of charge controller using eq. (3.20)

= 9.8 kA

B, **Design steps of solar panel for May Shih village**

40% of the energy will be (0.4x 1215 kWh /day) = 486 kWh/day

Assuming a 20% loss on the system

Total energy demand = 583 kWh/day

Selection of PV module

PV module with a PV module with a 635W N-type Mono-crystalline solar panel is selected for this project design.

The battery type selected is a Li-ion LFP system, which is Iron Edison LFP1400Ah-48v, they are known for their high energy density, long cycle life, and efficient performance. It needs a nominal capacity of around 1400Ah.

Table 4. 2: Solar panel design results for May Shih village

Total energy demand	583 kWh/d	Modules in parallel	337
System voltage	48V	Solar panel area	143.3 m2
Solar insulation of the site	4.04 kWh/m2/day	Battery load	25 kAh
System charges current	3 A	Battery capacity	100 kAh
PV cell temperature	52℃	Numbers of battery	71
Number of modules	340	Controller size	5.7 kA
Modules in string	1.01		

C, **Design steps of a solar panel for Mayderhu village**

50% of the energy will be (0.5x 785 kWh /day) = 392.5 kWh/day

Assuming a 20% loss on the system,

Total energy demand = 471 kWh/day

Selection of PV module

PV module with a 635 W N-type Mono-crystalline solar panel is selected for this project design.

The battery type selected is a Li-ion LFP system, Iron Edison LFP 1400Ah-48v. It needs a nominal capacity of around 1400Ah.

Table 4. 3 : Result of solar system design for Mayderhu village

Total energy demand	471 kWh/d	Modules in parallel	261
System voltage	48V	Solar panel area	112 m^2
Solar insulation of the site	4.2 kWh/m2/day	Battery load	16.3 kAh
System charges current	2.3 A	Battery capacity	64.3 kAh
PV cell temperature	52℃	Numbers of battery	46
Number of modules	264	Controller size	4.4 kA
Modules in string	1.01		

A **Design steps of wind turbine for Felege Mayat village**

From the total demand load, 30% of the energy will be covered by the wind turbine system so the theoretical power of the turbine will be

= 502 $kWh/_{day}$

System energy loss is approximately 20% loss,

P_T= 602 $kWh/_{day}$

C_p Assumed to be 0.4 for the design system

Blade Design Procedure

Annual energy consumption required = 219,730 kWh

Coefficient of performance, C_p = 0.40

Density of air = 1.221 $kg/_{m^3}$

Wind speed at a 30-meter height is 5.71 m/s.

Capacity factor (C_f) = 80% =0.8

The power density of wind (ideal) using eq. (3.24)

= 113.6 $\frac{watt}{m^2}$

Actual power density from eq. (3.25)

= 45.46 $\frac{watt}{m^2}$

Calculate annual power density using eq. (3.26)

= 398 $kWh/_{m^2}$

Real annual power density from eq. (3.27)

= 318.4 $kWh/_{m^2}$

The area of the turbine can be estimated from eq. (3.28)

= 690 m^2

Calculate the radius of the rotor blade covered area from eq. (3.29)

R = 15 m

Calculate the Power rating of the turbine using eq. (3.30)

= 31 kW

No. of turbines required = $25/_{31}$ = 1

Therefore, to produce 219.7 MWh of electricity annually (with a rated average wind speed of 5.71m/s), we need 1 number of turbines (rated 31 kW).

B. **Design steps of wind turbine for May Shih village**

From the total demand load, 30 % of the energy will be covered by the wind turbine system so the theoretical power of the turbine will be

= (0.3x 1215$kWh/_{day}$) = 364.5 $kWh/_{day}$

The estimation of the system energy loss is approximately 20% loss,

P_T= 437 $kWh/_{day}$

Blade Design Procedure

Annual energy consumption required = 159,505 kWh

Coefficient of performance, C_p = 0.40

Density of air = 1.221 $kg/_{m^3}$

Wind speed at a 30-meter height is 6.96 $m/_s$

Capacity factor (C_f) = 80% =0.8

Table 4. 4: Result of wind design for May Shih

Theoretical power	437 $kWh/_{day}$

Annual energy consumption	159,505 kWh
C_p	0.4
Wind speed at 30m height	6.96 $m/_s$
Power density	205.8 $\frac{watt}{m^2}$
Actual power density	82 $\frac{watt}{m^2}$
Annual power density	721 $kWh/_{m^2}$
Real annual power density	577 $kWh/_{m^2}$
Area of the rotor	276 m^2
Radius of blades	9.4 m
The power rating of the turbine	23 kW
Number of turbines	1

Therefore, to produce 160 MW of electricity annually (with a rated average wind speed of 6.96 m/s), we need 1 turbine (rated 23 kW).

C. **Design steps of wind turbine for Mayderhu village**

From the total demand load, 30 % of the energy will be covered by the wind turbine system so the theoretical power of the turbine will be

= (0.3x 785$kWh/_{day}$) = 235.5 $kWh/_{day}$

The estimation of the system energy loss is approximately 20% loss,

P_T= 283 $kWh/_{day}$

Blade Design Procedure

Annual energy consumption required = 103,295 kWh

Coefficient of performance, C_p = 0.40

Density of air = 1.221 $kg/_{m^3}$

Wind speed at a 30-meter height is 6.03 $m/_s$

Capacity factor (C_f) = 80%

Table 4. 5: Result of wind design of Mayderhu

Theoretical power	283 $kWh/_{day}$
Annual energy consumption	103,295 kWh
C_p	0.4
Wind speed at 30m height	6.03 $m/_s$
Power density	134 $\frac{watt}{m^2}$
Actual power density	54 $\frac{watt}{m^2}$
Annual power density	473 $kWh/_{m^2}$
Real annual power density	378 $kWh/_{m^2}$
Area of the rotor	273 m^2
Radius of blades	9.3 m
The power rating of the turbine	15 Kw
Number of turbines	1

Therefore, to produce 103 MW of electricity annually (with a rated average wind speed of 6.03m/s), we need 1 turbine (rated 15 kW).

A. **The design component of biomass energy for Felege Mayat**

- The number of cows in the village is an average of 1950
- The average cow dung discharge is = 8- 10 kg/cow dung/day [23]

TS_d= 1950 * 8 = 15,600 kg / cow-day

Therefore, the daily biomass input is 15,600 kg.

Daily Biogas Generation (G_d) = Volatile Solids (VS) Loading Rate × Biogas Yield

Where:

VS = Total Solids (TS) Content × Total Daily Feedstock × volatile Solids (VS) Fraction

Total solids (TS) content of the feedstock (%) = 16%

Volatile solids (VS) fraction of the total solids (%) = 80%

Biogas yield of the feedstock (m³/kg of VS) = 0.35 $m^3/_{kg}$ of VS

VS Loading Rate = $0.16 \times 15{,}600\ kg \times 0.8 = 1996.8\ kg\ of\ VS\ per\ day$

Daily Biogas Generation using eq. (2.25)

G_d = 1996.8 $kg\ of \frac{VS}{day} \times 0.35\ {m^3}/{kg\ of\ VS} = 698.8\ {m^3}/{day}$

Therefore, the daily biogas generated from the cow dung-based anaerobic digestion system would be 698.8 ${m^3}/{day}$.

Sizing Biogas Digester

Calculate Dry matter (D_m) of fresh discharge using eq. (3.32)

= 15,600 ${kg}/{day}$ *0.16 = 2496 ${kg}/{day}$

- To make a favorable condition for fermentation the concentration of organic dry matter should be 8% i.e., 8 kg Organic dry matter should be available in 100 kg influent.

8 ${kg}/{day}$= 100 ${kg}/{day}$

2496 ${kg}/{day}$ = X

X = 31,200 ${kg}/{day}$

Water should be added to make the discharge an 8% concentration of organic dry matter:

m_{water}= 31,200 – 15,600 = 15,600 ${kg}/{day}$

Assuming the density of slurry is approximately 1000${kg}/{m^3}$,

The volume of daily discharge of substrate is calculated using eq. (3.33)

=$\frac{31,200kg}{1000{kg}/{m^3}}$= 31.2 m^3

The volume of the digester is calculated by using eq. (3.34) and the value is 1872 m^3

By using eq. (3.35) the value of V_d is 1173 m^3

From the geometrical assumptions in Table 3.6 and eq. (3.36)

80% V = 1173 m^3 , V= 1466 m^3

Now by using the formulas from Table 3.6, I calculate the following values

D = 14.8 m

V_1= 268 m^3, V_2=164.4 m^3 , V_3= 1018.5 m^3

From

V_3= we can calculate the value of 'H'

$V_3=\frac{\pi D^2 H}{4}$ →H =6 m

R_1= 10.75 m, R_2= 15.7 m

f_1= 3 m, f_2= 1.85 m

$V_c \leq 5\%$ V ~V_c = 5% V

V_c = 5% V= 58.5 m^3

Calculate the volume of biogas composition by using eq. (3.37) and Table 3.7

By using Table 3.8 and eq. (3.38) Calculate the mass for the Composition of biogas

Calculate the number of moles of the biogas using eq. (3.39)

Calculate the partial pressure using eq. (3.40)

Table 4. 6: Volume, mass, mole, and pressure of the gases

Volume	Value	Mass	Value	Mole	Value	Pressure	Value
V_{CH_4}	419.3 m^3/day	m_{CH_4}	281 kg/day	n_{CH_4}	17519 mol/day	P_{CH_4}	64kPa
V_{Co_2}	244.6 m^3/day	m_{CO_2}	474.5 kg/day	n_{CO_2}	10781 mol/day	P_{CO_2}	39kPa
V_{H_2}	35 m^3/day	m_{H_2}	3 kg/day	n_{H_2}	1489mol/day	P_{H_2}	5.4 kPa
V_{N_2}	7 m^3/day	m_{N_2}	8.4 kg/day	n_{N_2}	300mol/day	P_{N_2}	1.2 kPa
V_{H_2o}	2.1 m^3/day	m_{H_2o}	1.68 kg/day	n_{H_2o}	93 mol/day	P_{H_2o}	0.3 kPa
V_{H_2S}	7 m^3/day	m_{H_2S}	9.8 kg/day	n_{H_2S}	287.5 mol/day	P_{H_2S}	1 kPa

The biogas saturates with water vapor and now the total pressure inside the digester is the sum of two pressures the dry gases and the water vapor.

At 33℃ temperatures, I can obtain by interpolation

At T_1 = 30 ℃, P_1 = 31.8mmHg

At T_2 = 37 ℃, P_2= 47.07mmHg

P_{H_2O}= 38.32 mmHg= 5.1 kPa

Total pressure developed in the gasholder ($\boldsymbol{P_{total}}$)

P_{total}=$P_{CH_4}+P_{CO_2}+P_{H_2O}+P_{H_2S}+P_{N_2}+P_{H_2}$

P_{total}= 62.5 kPa +40 kPa + 5.1 kPa + 1 kPa + 1.08 kPa +5.27 kPa

P_{total} = 114.95 kPa

At p = 1.013bar, and T = 300K Assuming the biogas kinematic viscosity is equal to the air γ = 1.568× 10−5 m2/s

From eq. (2.38) calculate the flow rate by assume 8 hours of usage time, discharge is

Q= 11.2 $m^3/hour$

The area of the pipe will be

Assume, d= 6 cm = 0.06 m

A= $\frac{\pi d^2}{4} = 2.83 * 10^{-3}\ m^2$

V = $\frac{Q}{A} = \frac{11.2\ m^3/hour}{2.83*10^{-3}\ m^2}(\frac{1\ hour}{3600\ sec})$ = 1.1 m/s

By using eq. (2.43) calculate R_e

R_e =4209.2, since it is greater than 2300 the flow is turbulent. So that to calculate the friction factor for pipe we use eq. (2.42), f = 0.039

Calculate head loss due to friction in pipes using eq. (3.48)

h_f= 0.6 m

Whereas,

L = 15m

Calculate head loss due to Bends using eq. (3.52)

$h_{m,b}$=0.61 m

Whereas,

K_b= a dimensionless coefficient that depends on the bend radius/pipe radius ratio and the angle of the bend.

K_b= 0.5 for elbow connection and considering the average number of elbows 20.

V = velocity of the pipe (i.e., = 1.1 m/s)

Calculate head loss due to valves using eq. (3.53) and Table 3.9

The expression gives the head loss due to a valve

$h_{m,v}$=0.37 m

For the gate valve, fully open K_v= 0.2

n_{valve}= average number of valves = 30

Calculate head loss due to sudden contraction in the area of flow using eq. (3.54) and Table 3.10

By using eq. (3.55) I calculate the areas

$A_1 = \frac{\pi {D_1}^2}{4}$, $A_2 = \frac{\pi {D_2}^2}{4}$

Now the diameter will be

D_1 = 0.06 m , D_2= 0.03 m

$V_1 = 1.1\ m/s$

$= \frac{\pi {D_1}^2}{4} V_1 = \frac{\pi {D_2}^2}{4} V_2$

$V_2 = 4.4\ m/s$

But

$A_1 = \frac{\pi (0.06\ m)^2}{4} = 2.83 * 10^{-3}\ m^2$, $A_2 = \frac{\pi (0.03\ m)^2}{4} = 7 * 10^{-4}\ m^2$

$\frac{A_2}{A_1} = \frac{7 * 10^{-4}\ m^2}{2.83 * 10^{-3}\ m^2} = 0.25$

So, the value of K will be found by interpolating the value of the area ratio

At $\frac{A_2}{A_1}$ = 0.3, the value of K= 0.36

At $\frac{A_2}{A_1}$ = 0.05, the value of K= X = 0.06

At $\frac{A_2}{A_1}$ =0.25 = the value of K is

K= 0.36−0.06 = 0.3

$h_{m,c}$= 0.3 m

Total head loss ($\boldsymbol{h_{f,total}}$)

$h_{f,total} = h_{m,c} + h_{m,v} + h_{m,b} + h_f$ = 1.88 m

Calculate total pressure loss in pipes using eq. (3.56)

$P_{f,total} = 1.221\ kg/m^3 * 9.81\ \frac{m}{s^2} * 1.88\ m$= 0.022 kPa

Calculating Compression ratio

In this work, the Compressor fulfills the following criteria that might be selected from the catalog for compression purposes.

- The gas being handled is biogas
- Flow rate = 162 m^3/hr for compressor selected from the catalog

- Suction pressure: The pressure at the compressor inlet expressed (Total pressure developed in the gasholder)

  P_s=114.95 kPa = 1.1495 bar
- Discharge pressure: The pressure at the compressor discharge expressed

  P_d= 11 bars
- Suction temperature =33℃

For the selection of Compressor Cylinder material

Table 4. 7: Compressor Specification

Model	Code	Pump	Tank Lt.	Air displaces l/min	Power		Max press.		Size mm	Weight kg
					HP	Kw	Bar	Psi		
BV8900/1000	7PV9X5	BV8900	1000	2400	20	15	11	160	1430x930x1770	584

The pressure at the compressor discharge was expressed

P_d= 11 bars

So, now

$P_s = P_{total,partial\ P\ of\ biogas} + P_{atmo}$ =2.1625 bar-a

$P_d = P_{copressor\ descharge} + P_{atmospheric}$ =11 bar + 1.013bar =12.013 bar-a

Therefore, calculate the compression ratio using eq. (3.57)

R= 5.58

By the value of R =5.58, the chosen compressor is the two-stage compressor from Table 3.11

Energy density and storage volume of plant

By using eq. (3.58) I calculate V_2

Substituting the values

$$V_2=V_1 * \sqrt[k]{\frac{P_1}{P_2}} = 89.6\ {m^3}/{day} * \sqrt[1.3]{\frac{114.95\ kPa}{1100\ kPa}} = 15.7\ {m^3}/{day}$$

Therefore, to ensure a steady supply of compressed raw biogas for electrification, it is first stored in a pressure vessel which has a storage capacity of 15.7 m^3 since another volume is stored in the compressor.

Composition of biogas

CH_4 = 60% Vol, i.e., $\frac{V_{CH_4}}{V_{tot}}$ = 0.6

CO_2= 40% Vol, i.e., $\frac{V_{CO_2}}{V_{tot}}$ = 0.4

Traces of other components are negligible

- temperature: T = 298 K (25°C)
- pressure, ambient: P_a = 950 mbar
- pressure in biogas plant: P_p= 20 mbar, gauge

Step 1: total pressure of biogas, P_T

P_T= 950 + 20 = 970 mbar $0.97 * 10^5$ Pa

If the humidity of biogas is not considered in the gas analysis so far, the value has to be corrected using the diagram.

Step 2: Density ρ of CH_4 in the mixture at actual pressure P and temperature T, calculated based on the table values at standard conditions from Eq. (3.61)

Step 3: the actual calorific value of the given biogas from Eq. (3.62)

$H_{u,act}$=18,650 $^{kJ}/_{m^3}$

- Energy consumption (flow) of the engine at rated power using Eq. (3.64)

= 10 $\frac{m^3n}{h}$ $*$25000 $\frac{kJ}{m^3n}$

=250,000 $^{kJ}/_{hr}$

- Actual biogas consumption (The volumetric fuel consumption or supply) fc of the engine at rated power

$$f_c = \frac{E}{H_{u,act}} = \frac{250000\ ^{kJ}/_{hr}}{18650\ ^{kJ}/_{m^3}} = 13.4\ ^{m^3}/_{hr}$$

Stoichiometric air/fuel ratio

On a mass basis at the combustion of CH_4 with air is complete but without unutilized excess air

$$\frac{m_{CH_4}}{m_{air}} = \frac{1\ kgCH_4}{14.5\ kg\ air} = 0.0689$$

- H_2S Content should be at 0.15 Vol % (1500 ppm), but never more than 0.5 Vol % (5000 ppm)

- ❖ Calorific value of biogas by methane content 100% CH_4: H_u = 36 000 $\frac{kJ}{m^3n}$ = 10 $\frac{kWh}{m^3n}$each 10% of CH_4 content in biogas: H_u = 3600 $\frac{kJ}{m^3n}$ = 1 $\frac{kWh}{m^3n}$
- ➢ 65 % CH_4: H_u = 23 400 $\frac{kJ}{m^3n}$ = 6.5 $\frac{kWh}{m^3n}$

Thermodynamic properties of CH_4 at 273 K and 101325 Pa are:

- ➢ specific treat C_p= 2.200 $^{kJ}/_{kgK}$
- ➢ molar mass M = 16.04 $^{kg}/_{kmol}$
- ➢ density ρ = 0.657 $^{kg}/_{m^3}$
- ➢ the individual gas constant R = 0.518 $^{kJ}/_{kgK}$
- ➢ lower calorific value H_u= 50000 $^{kJ}/_{kg}$, $H_{u,n}$= 36000 $\frac{kJ}{m^3n}$

The actual calorific value of biogas is a vital parameter for the performance of an engine and can be calculated by using the following equation.

$H_{u,act}$= $\rho_{CH_4,act.} * \frac{V_{CH_4}}{V_{tot}} * H_{u,n.}$

V_{CH_4}= 53.76m^3, V_{tot}= 89.6m^3, $\rho_{CH_4,act.}$= 0.657$^{kg}/_{m^3}$, H_u= 50000 $^{KJ}/_{kg}$

$$H_{u,act} = 19{,}710 \ ^{KJ}/_{m^3}$$

The fuel consumption of an IC engine using biogas is often specified in$\frac{m^3n}{h}$ or$\frac{m^3n}{kWh}$. The standard cubic meter (m^3n) means a volume of 1 cubic meter of gas under standard conditions (273 K and 10132 Pa). Technical parameters of biogas are very important because of their effect on the combustion process in an engine. Those properties are:

- ➢ Ignitability of CH_4 in mixture with air:

CH_4= 5-15 Vol. %

Air = 95-85 Vol. %

Methane will ignite only when its concentration in air is between these limits. Concentrations below 5% or above 15% will not support combustion.

Therefore, for my case, I have selected the Ignitability of CH_4 in a mixture with air:

CH_4= 10 % Vol.

Air = 90 % Vol.

- Combustion velocity in a mixture with air at P = 1 bar:

cc = 0.38 m/s at 10% CH_4

B. **Design component of biomass energy for May Shih**

- The number of cows found on the site is 1386 cows

TS_d= 1386 * 8 = 11,088 kg / cow-day

Table 4. 8: Result of biomass design for May Shih

G_d	$496.7\, m^3/day$	D	13.2m	R_1	9.57m	Q	$14.1 m^3/h$	A_2	$7 * 10^{-4}\, m^2$
D_m	$1774\, kg/day$	V_1	$190m^3$	R_2	14m	D	0.06m	V_2	$5.5 m/s$
V_s	$22\, m^3/day$	V_2	$115m^3$	f_1	2.64m	A_1	$2.83 * 10^{-3}\, m^2$	$\frac{A_2}{A_1}$	0.25
V_d	$823\, m^3/day$	V_3	$722m^3$	f_2	1.65m	V_1	$1.38 m/s$	$h_{f,total}$	1.72m
V	$1029m^3$	H	5.3m	V_c	$41m^3$	R_e	5280	$P_{f,total}$	$0.035\, kPa$

Table 4. 9:Volume, mass, moles, and pressure of gases

V_{CH_4}	$298\, m^3/day$	m_{CH_4}	$197\, kg/day$	n_{CH_4}	$12444 mol/day$	P_{CH_4}	$64\, kPa$
V_{CO_2}	$174\, m^3/day$	m_{CO_2}	$337 kg/day$	n_{CO_2}	$7662\, mol/day$	P_{CO_2}	$39\, kPa$
V_{H_2}	$25\, m^3/day$	m_{H_2}	$2.2\, kg/day$	n_{H_2}	$1092 mol/day$	P_{H_2}	$5.6\, kPa$
V_{N_2}	$5\, m^3/day$	m_{N_2}	$6\, kg/day$	n_{N_2}	$214 mol/day$	P_{N_2}	$1.2\, kPa$
V_{H_2o}	$1.5\, m^3/day$	m_{H_2o}	$1.8\, kg/day$	n_{H_2o}	$100\, mol/day$	P_{H_2o}	$0.5\, kPa$
V_{H_2s}	$5\, m^3/day$	m_{H_2s}	$7\, kg/day$	n_{H_2s}	$205.4 mol/day$	P_{H_2s}	$1\, kPa$

C. **Design component of biomass energy for Mayderhu**

- The number of cows found on the village are 924 cows

TS_d= 924 * 8 =7392 kg / cow-day

Table 4. 10: Result of biomass design for Mayderhu

G_d	$331\, m^3/day$	D	11.6m	R_1	8.4m	Q	$14.1 m^3/h$	A_2	$7 * 10^{-4}\ m^2$
D_m	$1183\, kg/day$	V_1	$129 m^3$	R_2	12m	D	0.06m	V_2	$5.5 m/s$
V_s	$15\, m^3/day$	V_2	$78 m^3$	f_1	2.3m	A_1	$2.83 * 10^{-3}\ m^2$	$\frac{A_2}{A_1}$	0.25
V_d	$557\, m^3/day$	V_3	$490 m^3$	f_2	1.45m	V_1	$1.38 m/s$	$h_{f,total}$	1.65m
V	$696 m^3$	H	4.6m	V_c	$28 m^3$	R_e	5280	$P_{f,total}$	$0.035\ kPa$

Table 4. 11: Volume, mass, moles, and pressure of gases

V_{CH_4}	$197\ m^3/day$	m_{CH_4}	$133\, kg/day$	n_{CH_4}	$8292\, mol/day$	P_{CH_4}	$64\ kPa$
V_{CO_2}	$116\ m^3/day$	m_{CO_2}	$225\, kg/day$	n_{CO_2}	$5103\, mol/day$	P_{CO_2}	$39\ kPa$
V_{H_2}	$16.5\ m^3/day$	m_{H_2}	$1.5\, kg/day$	n_{H_2}	$730\, mol/day$	P_{H_2}	$5.6\ kPa$
V_{N_2}	$3.3\ m^3/day$	m_{N_2}	$4\, kg/day$	n_{N_2}	$143\, mol/day$	P_{N_2}	$1.2\ kPa$
V_{H_2o}	$1\ m^3/day$	m_{H_2o}	$0.8\, kg/day$	n_{H_2o}	$44\, mol/day$	P_{H_2o}	$0.34 Pa$
V_{H_2s}	$3.3\ m^3/day$	m_{H_2s}	$4.6\, kg/day$	n_{H_2s}	$135\, mol/day$	P_{H_2s}	$1\ kPa$

4.2 Modeling of Hybrid System with HOMER

This chapter deals with optimization results for the selected combined power system for the three villages and is discussed thoroughly after carefully inputting all of the considered input variables into the software, it runs to get feasible results. In the results, the categorized table presented the least cost-effective combination among all component setups.

A. In Felege Mayat village, different renewable energy resources are found. So, 50% of the power demand will be covered by the solar system wind turbines will cover 35% of the demand for power, and the rest 15% will be covered by biomass.

B. In May Shih, different renewable energy resources are found. It needs the most effective and efficient design. So, 40% of the power demand will be covered by the solar system wind turbines will cover 40% of the power demand, and the rest 20% will be covered by biomass.

C. In Mayderhu village different renewable energy resources are found to achieve the demand. So, 40% of the power demand will be covered by the solar system, wind turbines will cover 40% of the power demand, and the rest 20% will be covered by biomass.

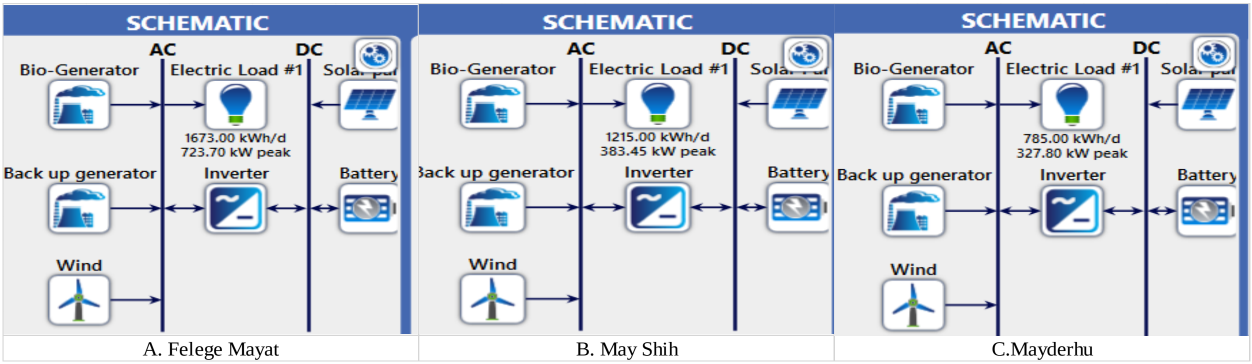


Figure 4. 1: Hybrid system of the sites

4.3 Connected Electric Load

The electrical load is an electrical component or portion of a circuit that consumes electric power, the data were calculated for the total hourly basic daily electrical load requirement of the villages, The Daily load requirement of the intended Felege Mayat village is 1673 kWh/day and the peak load is found to be 723.7 kW, for Mayderhu village is 785 kWh/day and the peak load is 327.8kw and for the third May Shih village the electric load is 1215 kWh/day and the peak load is 383.45kW.

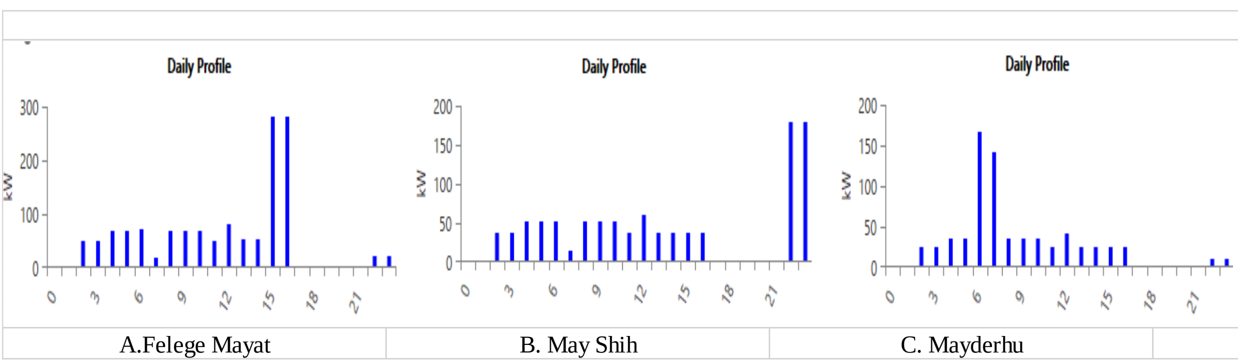


Figure 4. 2: Daily electric profile of the site

4.4 Inputs of Each Component to Homer Software

Table 4. 12: Size, cost, quantity, and lifetime input for Homer software

Component Type	Site	Size(kW)	Capital ($)	Replacement ($)	O&M ($/year)	Quantity	Lifetime (year)

PV Module	Felege	362	60000	30000	240	590	25
	Shih	153	25000	12500	100	340	25
	Derhu	164	30000	15000	120	261	25
Biomass generator	Felege	160	25000	12500	0.5	1	60000hr
	Shih	115	18000	9000	0.3	1	60000hr
	Derhu	70	12000	6000	0.2	1	60000hr
Wind	Felege	30	57000	39000	220	1	25
	Shih	25	48000	33000	190	1	25
	Derhu	20	38500	27000	154	1	25
Battery	Felege	98	8000	5000	40	98	20
	Shih	71	8000	5000	40	71	20
	Derhu	46	8000	5000	40	46	20
Inverter	Felege	903	7500	5000	50	1	15
	Shih	478	4000	2500	26	1	15
	Derhu	408	3500	2000	23.3	1	15
Backup generator	Felege	728	30000	15000	0.33	1	90000hr
	Shih	400	25000	12500	0.27	1	90000hr
	Derhu	360	20000	10000	0.22	1	90000hr

4.5 Simulation Result

The simulation output is a list of feasible combinations of Wind/ PV/Biomass/Inverter, and Battery hybrid system setup. The below Tables show the categorized simulation result, which represents the optimization result. The best energy systems were selected with less net present cost (NPC), minimum cost of energy (COE), high renewable fraction, less excess electricity, and less fuel consumption. The maximum annual capacity shortage and minimum renewable fraction are the worst constraints case.

4.5.1 Overall Optimal Results for Felege Mayat

Table 4. 13: Compare the proposed and base system

Parameters	Base system	Proposed system
NPC	$227,285	$109,734

Initial investment	$133,007	$62,119
O&M	$15,028	$3683
LCOE	$0.0291	$0.014
CO_2	2239 kg/day	26 kg/day
Fuel consumption	2042 tons/yr.	23.7 tons/yr.

Table 4. 14: optimization results in a categorized form

time	PV (kW)	Wind	Bio	Back up	Battery	Inverter	NPC ($)	COE	RF (%)	Cap short (%)
1	142	16	160	0	88	656	109,734	0.014	100	0.04
2	0	23	160	0	82	596	113,944	0.0145	100	0.18
3	403	0	160	0	86	582	122,850	0.0156	100	0.16
4	170	17	160	728	66	664	141,640	0.0179	100	0
5	0	28	160	728	96	636	145,818	0.0185	100	0

Based on the total net present cost: As shown in above Table 4.3, the configuration of system 1, has less net present cost than the other systems, which is about $109,734 with the combination of Bio-generator/Solar panel/Wind/Battery. With less NPC system 1 is the winner.

Based on Levelized cost of energy: Rank 1 is registered as the least valued among all systems. For system 1 the COE is around $0.014.

Based on total fuel consumption: The lower diesel consumption and the higher energy generation from renewable sources are recommended as a good choice. Systems 1, 3, and 5 didn't have a backup generator but ranks 2 and 4 use generators with fuel consumption of 188L and 553L respectively.

Based on excess electricity production: The lowest excess electricity production is the optimal system, which is first selected to implement. Ranks excess electricity production is 5.2%, 5.48%, 5.57%, 13.8%, and 17.5% respectively.

Based on the Emission value: All the ranks have different amounts of carbon dioxide output those are 26 kg/yr., 142 kg/yr., 188 kg/yr., 167 kg/yr., and 172 kg/yr. respectively.

4.5.2 Overall Optimal Results for May Shih

Table 4. 15: The difference between the base and the proposed system

Parameters	Base system	Proposed system
NPC	$154,794	$90,279
Initial investment	$22,821	$75,121
O&M	$10,209	$1173
LCOE	$0.0275	$0.0158
CO2	1562 kg/day	165 kg/day
Fuel consumption	1424 tons/yr.	150 tons/yr.

Table 4. 16: optimization results in a categorized form

Rank	PV (kW)	Wind	Bio	Back up	Battery	Inverter	NPC ($)	COE	RF (%)	Cap short (%)
1	285	0	115	0	53	399	90,279	0.0158	100	0.12
2	265	1	115	0	54	458	106,513	0.0186	100	0.1
3	352	0	115	410	58	473	121,418	0.0212	99.7	0
4	283	1	115	410	30	462	137,993	0.0241	99.6	0
5	0	1	115	0	20	187	154,714	0.0275	100	3

Based on the total net present cost: From Table 4.5, the system's configuration (rank 1), has a lower net present cost than the other ranks, which is about $90,279 with combination of Bio-generator/Solar panel/Battery.

Based on cost of energy: System A is listed as the least valued among all systems. For system A the COE is around $0.0158, for system B, it is about $0.0186.

Based on total fuel consumption: The first scenario is the lower feedstock consumption. From the listed situation, system A has consumed the lower feedstock, which is about 231 tons than system B, which has consumed 34.7 feedstock.

Based on excess electricity production: The lowest excess electricity production is the optimal system, which is first selected to implement. The systems have produced excess electricity of 5.5%.7.7%, 18%, 15.1%, and 0% respectively.

Based on the Emission value: All the ranks have different amounts of carbon dioxide output those are 165 kg/yr., 93.4 kg/yr., 111.3 kg/yr., 1379 kg/yr., and 1562 kg/yr. respectively.

4.5.3 Overall Optimal Results for Mayderhu

Table 4. 17: Compare the proposed and base system

Parameters	Base system	Proposed system
NPC	$107,006	$61,400
Initial investment	$19,313	$52,386
O&M	$6783	$698
LCOE	$0.0291	$0.0167
CO2	1022 kg/day	91.8 kg/day
Fuel consumption	932 tons/yr.	83.7 tons/yr.

Table 4. 18: optimization results in a categorized form

Rank	PV (kW)	Wind	Bio	Back up	Battery	Inverter	NPC ($)	COE	RF (%)	Cap short (%)
1	175	0	70	0	26	328	61,400	0.0167	100	1.2

2	140	1	70	0	27	328	67,174	0.0182	100	0.4
3	207	0	70	400	29	347	87,225	0.0235	99.3	0
4	160	1	70	400	28	351	89,788	0.0242	99.5	0
5	0	4	70	0	24	275	98,890	0.0256	100	1.3

Based on the total net present cost: As shown in Table 4.7, the configuration of the system (rank 1), has a lower net present cost than the other ranks, which is about $61,400, rank 2 is about $67,174, rank 3 is about $87,225, rank 4 is about $89,788 and rank 5 is $98,890.

Based on cost of energy: Rank 1 is selected as the least valued among all systems. The systems COE is $0.0167, $0.0182, $0.0235, $0.0529 &$0.0256 respectively. The lowest COE value is found in rank 1.

Based on total fuel consumption: The first scenario is the lower feedstock consumption. From the listed situation, system A has consumed the lower feedstock, which is about 47.5 tons than system B, which has consumed 50.7 feedstock. Thus, based on these measuring parameters and giving due merit for environmental protection system A is the best choice from the categorized systems.

Based on excess electricity production: The lowest excess electricity production is the optimal system. The systems produced different amounts of excess electricity which are 6.5%,5.5%,16.1%, 11.6% & 3.2% respectively.

Based on the Emission value: All the ranks have different amounts of carbon dioxide output are 91.8 kg/yr,78.6 kg/yr,1428 kg/yr.,1088 kg/yr. & 246 kg/yr. respectively.

4.6 Cost summary of the villages

4.6.1 Cost summary for Felege Mayat village

The largest cost is the wind turbine, which costs a total NPC of $45,504.86. PV took the second-highest total NPC which is around $24,703.16. The bio-generator is the third-placed scheme with a cost of $24,237.34. The inverter costs $7167, a Battery with 7070, and the price of Homer cycle charging costs $1051.71. The power system capital cost, the Net present cost is $109,734, the Levelized COE is $0.0139 and the operating cost is $3683.

4.6.2 Cost summary for May Shih village

Cost summary of the first optimal result, the largest cost is the solar panel, which costs a total NPC of $49,233. Bio-generator takes the second-highest total NPC which is around $29,638. The battery is the third-placed scheme with a cost of $6021. The inverter costs $4336, and the Homer cycle charges $1051.71. The power system capital cost, the Net present cost is $90,279 the Levelized COE is $0.0157 and the operating cost is $1173.

4.6.3 Cost summary for Mayderhu village

From cost summary, the largest cost is the Solar panel, with a total NPC of $33,708. Bio-generator took the second-highest total NPC which is around $18,347. The battery is the third placed scheme with a cost of $4683. The price of the Inverter is $3610. The power system capital cost, the Net present cost is $61,400, the Levelized COE is $0.0167 and the operating cost is $697.

4.7Electric production of the villages

4.7.1 For Felege Mayat village

The simulation result showed that the power system setup has an annual electricity production of 700,148 kWh/year. The power generation offered by wind turbines is the largest which is about 66.7% or 466,841 kWh /yr., followed by the solar panel which accounts for 32.2% or 225,419 kWh/yr., the third one is biogas generator which has the ratio of 1.13% or 7888. The renewable fraction of the system is 100%. The AC primary load accounts for 610,543 kWh/year. Excess electricity obtained from this scheme is about 36,497 kWh/year which accounts for 5.21% of the total energy produced. This scheme has a capacity shortage of 0.04% and this setup can be a good choice to implement at the site and the unmet load in this system is about 0.001%.

4.7.2 For May Shih Village

The simulation result showed that the power system setup has an annual electricity production of 508,108 kWh/year. The power generation offered by solar is the largest as presented in the above graph which is about 90.2% or 458,153 kWh /yr., followed by the bio-generator which accounts for 9.8% or 49,955 kWh/yr. The renewable fraction of the system is 100%. The AC primary load accounts for 442,935 kWh/year. Excess electricity obtained from this scheme is about 28,105 kWh/year, which accounts for 5.5% of the total energy produced. This scheme has a capacity shortage of 0.16% and this setup can be a good choice to implement at the site the unmet load in this system is about 0.12%.

4.7.3 For Mayderhu village

The power system setup has an annual electricity production of 329,585 kWh/year. The power generation offered by PV is the largest which is about 91.5% or 301,729 kWh /yr., followed by the Bio-generator which accounts for 8.45% or 27,856 kWh/yr. The renewable fraction of the system is 100%. The AC primary load accounts for 284,083 kWh/year. Excess electricity obtained from this scheme is about 21,467 kWh/year (6.5%), which. The scheme has a capacity shortage of 1.2% and this setup can be a good choice to implement at the site the unmet load in this system is about 0.85%.

4.8 Optimized System Outputs of the Villages

4.8.1 For Felege Mayat village

Wind turbine output: the wind nominal capacity generated from the system is 480kW, the capacity factor is 11.1%, and the total amount of electric production is 466,841 kWh/yr. and the levelized cost is 0.0075$/kWh. Thus, the actual electrical power output of the wind turbine is 189kW. This wind turbine plant generates the highest power (66.7%) of the overall energy generated.

Quantity	Value	Units
Total Rated Capacity	480	kW
Mean Output	53.3	kW
Capacity Factor	11.1	%
Total Production	466,841	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	189	kW
Wind Penetration	76.5	%
Hours of Operation	3,705	hrs/yr
Levelized Cost	0.00754	$/kWh

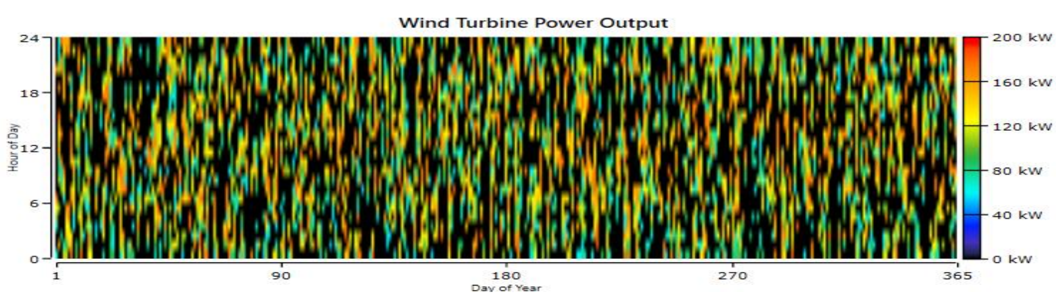


Figure 4. 3: Wind turbine output for Felege Mayat

PV output: The rated capacity of the PV array is 142 kW, the mean output is 25.7 kW, and the capacity factor is about 18.2%, total electric production is 225,419 kW h/yr., hour of operation 4372 and levelized cost is 0.008$/ kWh.

Quantity	Value	Units
Rated Capacity	142	kW
Mean Output	25.7	kW
Mean Output	618	kWh/d
Capacity Factor	18.2	%
Total Production	225,419	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	138	kW
PV Penetration	36.9	%
Hours of Operation	4,372	hrs/yr
Levelized Cost	0.00848	$/kWh

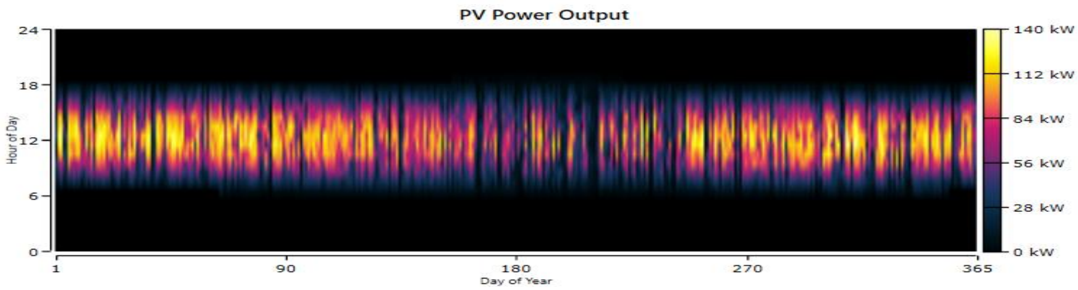


Figure 4. 4: Hourly and monthly Solar output of Felege Mayat

As displayed in Fig.4.4 electricity generation is higher at times of high solar radiation striking the earth's surface. October is the month that gets the largest amount of irradiation. Starting from May until the end of September, PV power energy production is lower than in the other months. Thus, the minimum power output is 0kW (from 0:00hr to 6:00hr and 18:00hr to 23:00hr).

Biogas Generator output: The following Fig.4.5 shows the power output and biogas generator power of the system.

Quantity	Value	Units
Hours of Operation	51.0	hrs/yr
Number of Starts	3.00	starts/yr
Operational Life	1,176	yr
Capacity Factor	0.563	%
Fixed Generation Cost	0.845	$/hr
Marginal Generation Cost	0.0171	$/kWh

Quantity	Value	Units
Electrical Production	7,888	kWh/yr
Mean Electrical Output	155	kW
Minimum Electrical Output	80.0	kW
Maximum Electrical Output	160	kW

Quantity	Value	Units
Fuel Consumption	23.7	tons/yr
Specific Fuel Consumption	2.10	kg/kWh
Fuel Energy Input	92,178	kWh/yr
Mean Electrical Efficiency	8.56	%

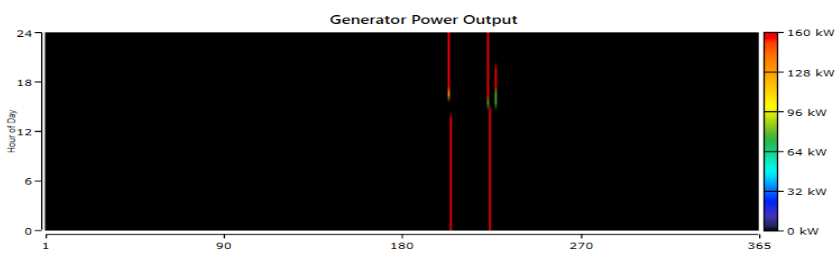


Figure 4. 5: Biogas Generator output of Felege Mayat

Bio generator participating in this hybrid power system bio generates a maximum power output of 160kW and, a minimum electrical output of 80kW. The amount of fuel consumed is around 23.7 tons per annum and the electrical production per year is 7888 kWh/yr.

4.8.2 For May Shih Village

PV output: The rated capacity of the PV array is 286 kW, mean output is 52.3 kW, and the capacity factor is about 18.3%, total electric production is 458,153 kW h/yr., hour of operation 4,431 and levelized cost is 0.008$ kW h.

Quantity	Value	Units
Rated Capacity	286	kW
Mean Output	52.3	kW
Mean Output	1,255	kWh/d
Capacity Factor	18.3	%
Total Production	458,153	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	280	kW
PV Penetration	103	%
Hours of Operation	4,431	hrs/yr
Levelized Cost	0.00831	$/kWh

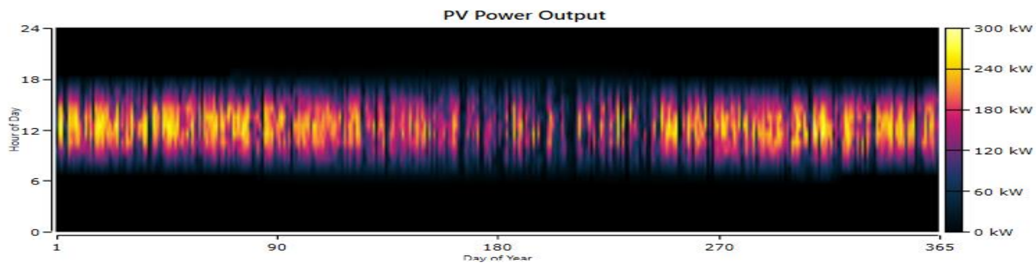


Figure 4. 6: Hourly and monthly Solar output of May Shih

As displayed in above Fig. the minimum power output is 0kW (from 0:00hr to 6:00hr and 18:00hr to 23:00hr).

Biogas Generator output: The Biogas generator participating in this hybrid power system has a maximum power output of 115kW and a minimum electrical output of 57.5kW. According to the simulation displayed the biogas generator's operating hours are 450 hrs./yr. The amount of fuel consumed is around 150 tons per annum. The electrical production per year is 49,955 kWh/yr.

Quantity	Value	Units
Hours of Operation	450	hrs/yr
Number of Starts	23.0	starts/yr
Operational Life	133	yr
Capacity Factor	4.96	%
Fixed Generation Cost	0.549	$/hr
Marginal Generation Cost	0.0171	$/kWh

Quantity	Value	Units
Electrical Production	49,955	kWh/yr
Mean Electrical Output	111	kW
Minimum Electrical Output	57.5	kW
Maximum Electrical Output	115	kW

Quantity	Value	Units
Fuel Consumption	150	tons/yr
Specific Fuel Consumption	2.10	kg/kWh
Fuel Energy Input	575,340	kWh/yr
Mean Electrical Efficiency	8.68	%

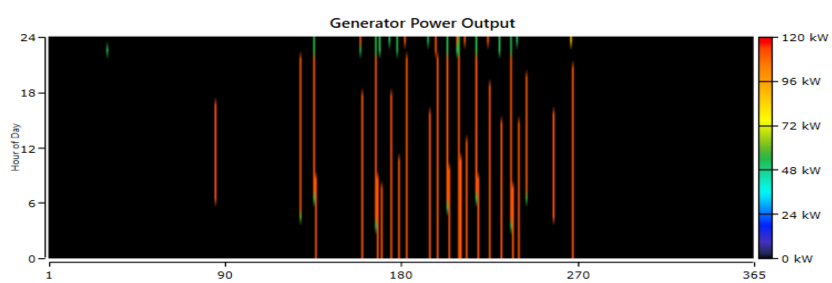


Figure 4. 7: Biogas Generator output of May Shih

4.8.3 For Mayderhu village

PV output: The rated capacity of the PV array is 175 kW, mean output is 34.4 kW, and the capacity factor is about 19.7%, total electric production is 301,729 kW h/yr., hour of operation 4,419 and levelized cost is 0.008$ kW h.

Quantity	Value	Units
Rated Capacity	175	kW
Mean Output	34.4	kW
Mean Output	827	kWh/d
Capacity Factor	19.7	%
Total Production	301,729	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	169	kW
PV Penetration	105	%
Hours of Operation	4,419	hrs/yr
Levelized Cost	0.00864	$/kWh

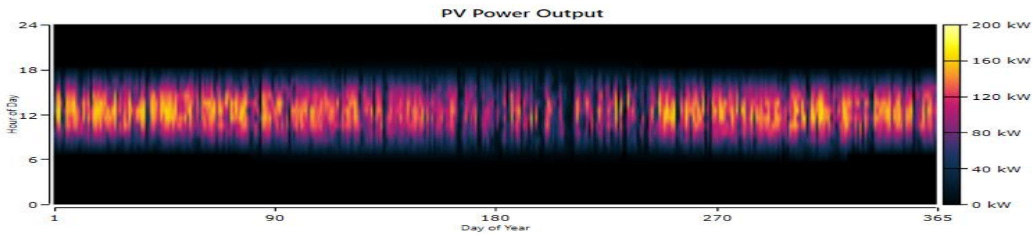


Figure 4. 8: Hourly and monthly Solar output of Mayderhu

As shown from the above Fig.4.8 the minimum power output is 0kW (from 0:00hr to 6:00hr and 18:00hr to 23:00hr).

Biogas Generator output: The Biogas generator participating in this hybrid power system has a maximum power output of 70kW and a minimum electrical output of 35kW. According to the simulation displayed the operating hours are 407 hrs./yr. The amount of fuel consumed is around 83.7 tons per annum. The electrical production per year is 27,856kWh/yr.

Quantity	Value	Units
Hours of Operation	407	hrs/yr
Number of Starts	31.0	starts/yr
Operational Life	147	yr
Capacity Factor	4.54	%
Fixed Generation Cost	0.360	$/hr
Marginal Generation Cost	0.0171	$/kWh

Quantity	Value	Units
Electrical Production	27,856	kWh/yr
Mean Electrical Output	68.4	kW
Minimum Electrical Output	35.0	kW
Maximum Electrical Output	70.0	kW

Quantity	Value	Units
Fuel Consumption	83.7	tons/yr
Specific Fuel Consumption	2.10	kg/kWh
Fuel Energy Input	325,337	kWh/yr
Mean Electrical Efficiency	8.56	%

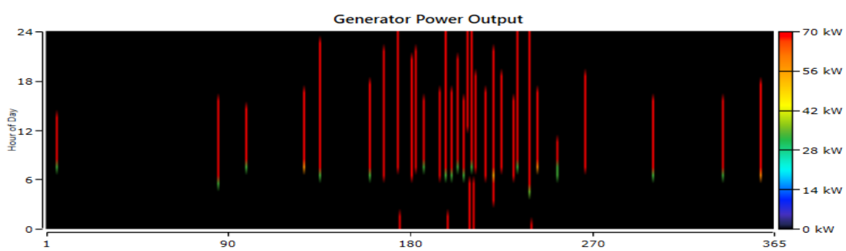


Figure 4. 9: Biogas Generator output of Mayderhu

4.9 Sensitivity Result

4.9.1 Felege Mayat village

In the sensitivity analysis, in Figure 4.10 capacity shortage and expected inflation rate are considered and in Figure 4.11 wind speed and average solar radiation are considered to evaluate the impact of different factors on the maximum system capacity as well as the net present cost and levelized cost of energy.

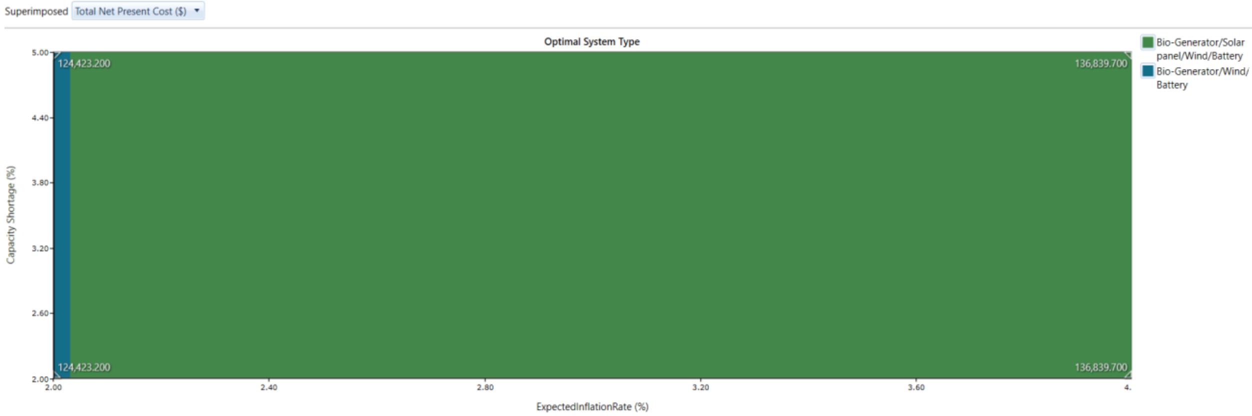


Figure 4. 10: sensitive analysis of expected inflation rate and capacity shortage

Figure 4.10 indicates that at any capacity shortage but when the expected inflation rate is 2 the best optimal system is Bio-generator/wind/battery but when the expected inflation rate is between above 2 the optimal system configuration is Bio-generator/solar panel/wind/wind/battery at minimum solar radiation 4 kWh/m2/day, minimum wind speed 4.4 m/s and at 1 bio-generator capital cost multiplier. The NPC is higher at the configuration of bio-generator/wind/battery.

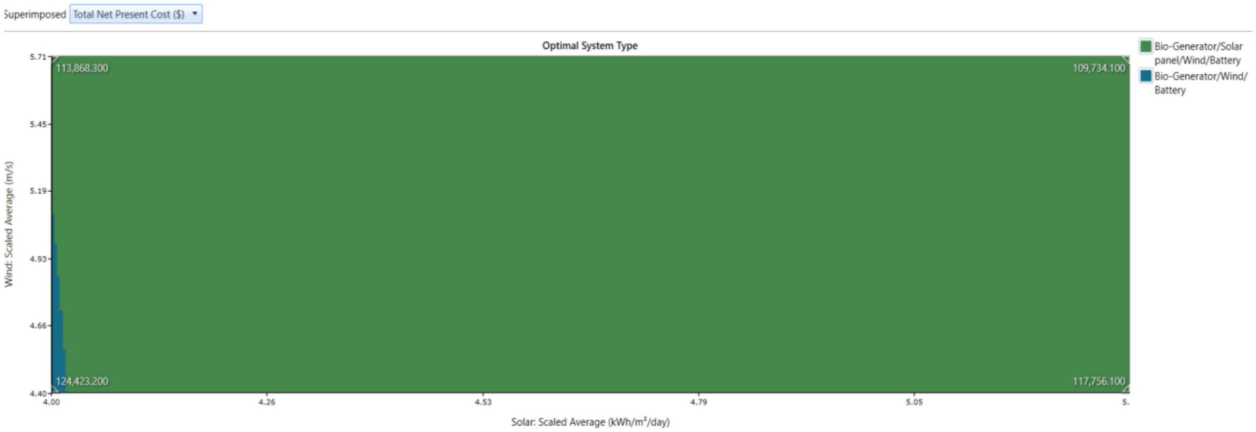


Figure 4. 11: Sensitivity analysis of wind speed and solar radiation

The above sensitivity result indicates that at lower scaled average solar radiation which is 4kWh/m2/day and at wind speed between 4.4m/s & 5.1m/s the optimal system is a Bio-generator/wind/battery, but at any point of wind speed and solar radiation above the lowest value the optimal configuration is Bio-generator/solar panel/wind/battery still the first optimal system has high NPC.

4.9.2 May Shih village

The optimal system configuration is a Bio-generator/solar panel/battery, as shown in the result when the scaled average solar radiation increases at a fixed value of solar panel capital cost multiplier the total net present cost decreases, but when the solar panel capital cost multiplier increases at fixed solar radiation the total net present cost also increases.

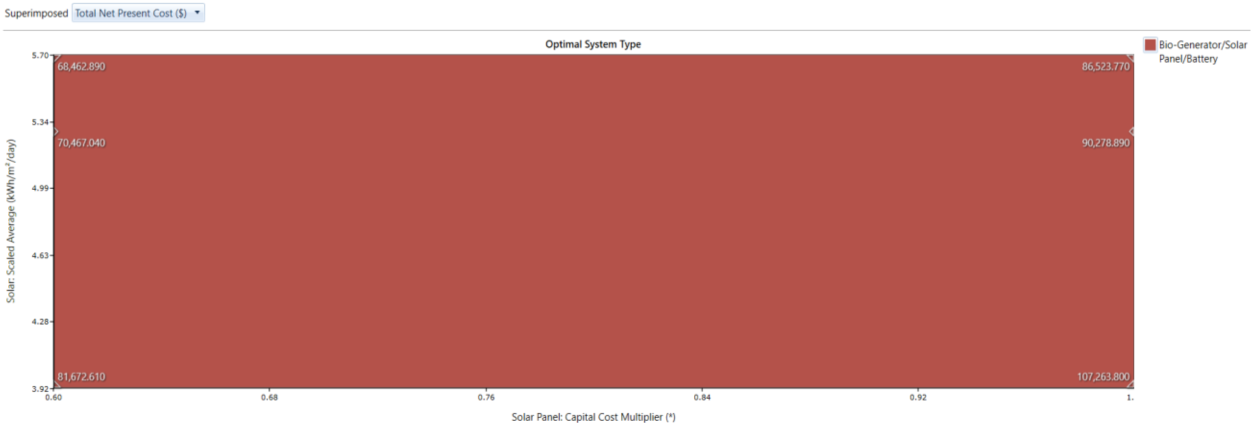


Figure 4. 12: Sensitivity analysis of solar radiation with cost multiplier of solar panel

4.9.3 Mayderhu village

Figures 4.13 show the respective sensitivities of the capital cost multiplier of a wind turbine to the expected inflation rate.

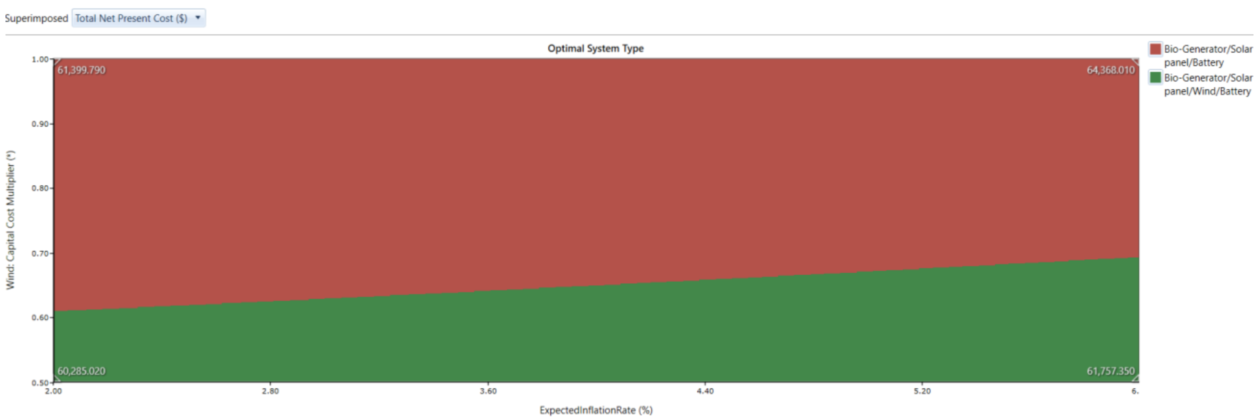


Figure 4. 13: Sensitivity analysis cost multiplier of wind turbine and expected inflation rate

The above figure reveals that the optimal system is a Bio-generator/solar/wind/battery when the capital cost multiplier is between 0.5 and 0.62. Also, there will be an optimal Bio-generator/solar/battery system when the wind capital cost multiplier is above 0.62 by putting the solar radiation and wind speed fixed at 5.7 kWh/m2/day and 6.03 m/s respectively for both configurations.

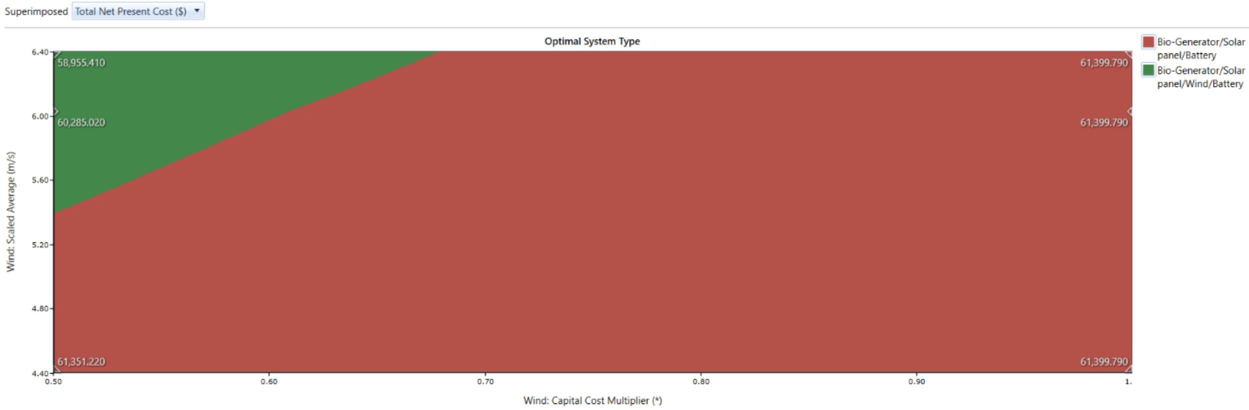


Figure 4. 14: Sensitivity analysis of wind speed and cost multiplier of wind turbine

Sensitivity analysis has also been carried out in Figure 4.14 showing the respective sensitivities of the wind speed to the capital cost multiplier of the wind turbine. The result shows the optimal systems of the Bio-generator/solar/battery system if the wind speed is between 4.4 and 5.4m/s and in all wind capital cost multipliers, the second one is the Bio-generator/solar/wind/battery when the wind speed is above 5.6 m/s and wind capital cost multiplier is between 0.5 and 0.7 at fixed solar radiation 5.7 kWh/m2/day for both optimal systems.

CHAPTER FIVE

Conclusions and Recommendation

5.1 Conclusion

The resource assessment conducted for the feasibility study of an integrated hybrid energy system in three villages of Ethiopia revealed significant potential for renewable energy utilization. The study identified the daily energy demands of Felege Mayat, May Shih, and Mayderhu villages as 1,673 kWh, 1,215 kWh, and 785 kWh, respectively. A thorough evaluation of local renewable resources indicated that the region is well-suited for harnessing wind, solar, and biomass energy. Solar insolation levels ranged between 5.3 and 6.2 kWh/m²/day, making solar photovoltaic systems a viable option. Additionally, wind energy potential was assessed, highlighting opportunities for integration with other renewable sources to enhance system reliability. Biomass resources, primarily derived from agricultural waste and livestock, also provided a sustainable energy solution.

The research findings indicate a promising economic outlook for the integrated hybrid energy system designed for off-grid rural electrification in the selected villages. The levelized cost of electricity (LCOE) was calculated at $0.0139/kWh for Felege Mayat, $0.0158/kWh for May Shih, and $0.0167/kWh for Mayderhu, demonstrating that the hybrid system is cost-effective and competitive with conventional energy sources. The result obtained by the simulation for Felege Mayat is Bio-generator/solar/wind/battery, for May Shih is Bio-generator/solar//battery, and for Mayderhu is Bio-generator/wind/battery are the least cost system with the NPC of $109,734. $90,279 and $ 61,400 and the excess energy production are 5.21%, 5.5%, and 6.5 %respectively.

The system reduces dependence on traditional biomass and diesel generators. Sensitivity analyses using HOMER software showed that even with fluctuations in energy prices and resource availability, the economic viability of the hybrid system remains strong. Overall, these economic metrics underscore the potential of the hybrid energy system to provide a reliable and affordable electricity supply.

From an Environmental Standpoint, the renewable energy fraction of the project is 100%, which implies the total energy almost obtained from Renewable Energy Resources. This study promotes clean energy and its contribution to the reduction of Pollutant emissions released to the environment

Socioeconomic Benefits: The proposed hybrid systems can empower rural communities, fostering economic development and social equity.

Moreover, this research emphasizes the dual benefit of addressing immediate energy access challenges while promoting environmental sustainability. This study serves as a foundation for future efforts to expand renewable energy solutions across Ethiopia and similar contexts, ultimately contributing to the broader goal of achieving universal energy access and active realization of Ethiopia's electrification objectives.

5.2 Recommendation

1. Conduct primary data collection to supplement existing secondary data. Engaging with local communities can provide insights into energy needs, resource availability, and potential barriers to implementation.
2. Expand the study to include additional villages or regions in Ethiopia. This would enhance the generalizability of results and provide a more comprehensive understanding of rural electrification challenges across diverse contexts.
3. Foster community involvement in the planning and implementation phases of hybrid energy systems. This can enhance social acceptance and ensure that the systems meet local needs.
4. Advocate for supportive policies and regulatory frameworks that promote renewable energy deployment and facilitate public-private partnerships. This can help to attract investment and improve access to financing for renewable energy projects.
5. It is imperative that the government establish a well-defined policy and, if needed, impose fines on consumers who fail to adopt energy-efficient items. This is because the country cannot reach its electrification goals solely by concentrating on increasing power generation. If every customer uses those goods, the area without electricity may experience disruptions in the saved energy.

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Appendix

Table A. 1: Population growth for 15 years

Year	Felege		Felege	May shih		Mayderhu	
N	Po	r	Pn	Po	Pn	Po	Pn
1	3600	0.025	3690	2944	3017.6	1968	2017.2
2	3600	0.025	3782.25	2944	3093.04	1968	2067.63
3	3600	0.025	3876.81	2944	3170.37	1968	2119.32
4	3600	0.025	3973.73	2944	3249.63	1968	2172.3
5	3600	0.025	4073.07	2944	3330.87	1968	2226.61
6	3600	0.025	4174.9	2944	3414.14	1968	2282.28
7	3600	0.025	4279.27	2944	3499.49	1968	2339.33
8	3600	0.025	4386.25	2944	3586.98	1968	2397.82
9	3600	0.025	4495.91	2944	3676.65	1968	2457.76
10	3600	0.025	4608.3	2944	3768.57	1968	2519.21
11	3600	0.025	4723.51	2944	3862.78	1968	2582.19
12	3600	0.025	4841.6	2944	3959.35	1968	2646.74
13	3600	0.025	4962.64	2944	4058.34	1968	2712.91
14	3600	0.025	5086.71	2944	4159.79	1968	2780.73
15	3600	0.025	5213.87	2944	4263.79	1968	2850.25

Table A. 2: Questionnaire translated from Tigrigna Language

1. Name of Respondent	6. How long do outages typically last? ☐ Less than 1 hour ☐ 1-3 hours More than 3 hours
2. Household Size • Number of adults • Number of children	7. What are your primary energy needs? (Rank from 1 to 5, with 1 being the most important) ☐ Lighting ☐ Cooking ☐ Injera mitad

	☐ Refrigeration Communication (e.g., phone charging)
3. Which type of stove do you use for injera baking? ☐ Three-stone fire stove ☐ Traditional closed mud stove ☐ Mirt fuel-efficient biomass stove ☐ Others	8. What do you know about the effect of the different types of fuel we use in a household e.g., global warming, deforestation, health problems? ☐ Good knowledge ☐ Medium knowledge ☐ None ☐ Other
4. What is the type of fuel used for injera baking? ☐ Wood chips ☐ Cow dung ☐ Forest and crop residues ☐ Others	9. Would you be willing to participate in community initiatives to improve energy access? ☐ Yes ☐ No
5. How frequently do you bake injera in a week?	10. Please share any additional comments or suggestions regarding energy access and needs in your community

3.2.1 Load Estimation for Felege Mayat Village

Table A. 3: Power consumption for low-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (75%)	kWh/d
Lamps	3	11	5	12:00-16:00 22:00-23:00	16.1	80.5
Mobile charger	2	15	3	13:00-16:00	14.64	43.92
Radio(working)	1	30	6	04:00-10:00	14.64	87.84

Radio(weekend)	1	30	9	07:00-16:00	14.64	131.76
Total						344

Table A. 4: Power consumption for high-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (25%)	kWh/d
Lamps	3	11	5	18:00-23:00	5.34	26.7
TV (weekday)	1	60	4	12:00-16:00	9.72	38.88
Tv(weekend)	1	60	6	06:00-08:00 12:00-16:00	9.72	58
Radio(weekday)	1	30	6	04:00-10:00	4.86	29.16
Injera Mitad	1	2850	0.5	15:00-15:30	461.7	230.85
Mobile charger	2	15	3	13:00-16:00	4.86	14.58
Total						398

Table A. 5: Power consumption of flour milling machine

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load	kWh/d
Flour milling	4	12,500	8	02:00-06:00 08:00-12:00	25	400
External lamp	2	40	8		0.08	0.64
Total						400.64

Table A. 6: Power consumption for health center

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (kW)	kWh/d
Room CFL	10	13	10	13:00-23:00	0.13	1.3
Toilet light	6	11	10	13:00-23:00	0.066	0.66
External light	3	40	10	13:00-23:00	0.12	1.2
Television	1	60	7	02:00-06:00 08:00-11:00	0.06	0.42
Desktop	1	150	7	0.2:00-06:00	0.15	1.05

				08:00-11:00		
Refrigerator	1	240	24	00:00-23:00	0.24	5.76
Mobile charger	10	15	3	06:00-07:00 12:00-14:00	0.15	0.45
Microscope	2	30	6	03:00-06:00 08:00-11:00	0.06	0.36
Total						11.2

Elementary School Load

Quality education for any community is essential for the socioeconomic development of one country. The school will have 15 classrooms proposed for the student learning process, and 1 administration office will be prepared. The school has to have 6 toilet rooms 2 for staff and 4 toilet rooms for students. the school will have 1 library. During the day there is no need for electricity for the classrooms Thus, most of the electricity will be utilized by computers and at minimal daytime. The largest load of the school will be recorded in the evening which is assumed for 4 classrooms when evening classes would be accompanying.

Table A. 7: Power consumption for school

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load	kWh/d
Class lamp	8	15	3	12:00-15:00	0.12	0.36
Toilet lamp	3	11	3	12:00-15:00	0.033	0.099
External lamp	2	40	3	12:00-15:00	0.08	0.24
Desktop	1	100	7	02:00-06:00 08:00-11:00	0.1	0.7
Printer	1	60	2	04:00-05:00	0.06	0.12
Staff room lamp	1	13	3	12:00-15:00	0.013	0.039
Total						1.558

The total energy needed for the village is the sum of all the loads that are described above

= **1155** $kWh/_{day}$

3.2.2 Load Estimation for May Shih Village

Table A. 8: Power consumption for low-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (75%)	kWh/d
Lamps	3	11	5	18:00-23:00	11.45	57.25
Mobile charger	2	15	3	13:00-16:00	10.41	31.23
Radio(working)	1	30	6	04:00-10:00	10.41	62.46
Radio(weekend)	1	30	9	07:00-16:00	10.41	93.69
Total						244.63

Table A. 9: Power consumption for high-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (25%)	kWh/d
Lamps	3	11	5	12:00-16:00 22:00-23:00	3.8	19
TV (weekday)	1	60	4	12:00-16:00	6.9	27.6
Tv(weekend)	1	60	6	06:00-08:00 12:00-16:00	6.9	41.4
Radio(working)	1	30	6	04:00-10:00	3.45	20.7
Injera Mitad	1	2850	0.5	15:00-16:00	327.75	163.8
Mobile charger	2	15	3	13:00-16:00	3.45	10.35
Total						283

Table A. 10: Power consumption for school

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load	kWh/d
Class lamp	6	15	3	12:00-15:00	0.09	0.27
Toilet lamp	3	11	3	12:00-15:00	0.033	0.099
External lamp	2	40	3	12:00-15:00	0.08	0.24
Desktop	1	100	7	02:00-06:00 08:00-11:00	0.1	0.7

Printer	1	60	1	04:00-05:00	0.06	0.06
Staff room lamp	1	13	3	12:00-15:00	0.013	0.039
Total						1.408

The elementary school has 12 classrooms in 3 blocks, also there is 1 staff office and they have 6 toilets 3 for women and 3 for men. The largest load of the school will be recorded in the evening the above load is calculated for the evening class light for 4 classrooms, 3 toilets, the staff office lamp, and 1 external light.

Power consumption for Flour milling is 300.64kWh/day

Power consumption for health center is 9.725 kWh/day

The total energy needed for the village is 839 kWh/day

3.2.3 Load Estimation for Mayderhu Village

I made the load estimation of 308 households with 70% having low income and the remaining 30% having high income in the below tables.

Table A. 11: Power consumption for low-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (70%)	kWh/d
Lamps	3	11	5	12:00-16:00 22:00-23:00	7.09	35.45
Mobile charger	2	15	3	13:00-16:00	6.45	19.35
Radio(working)	1	30	6	04:00-10:00	6.45	38.7
Radio(weekend)	1	30	9	07:00-16:00	6.45	58
Total						151.5

Table A. 12: Power consumption for high-income HHs

Appliance	Quality	Capacity(w)	Run-time(h/d)	Period	Peak load (30%)	kWh/d
Lamps	3	11	5	12:00-16:00 22:00-23:00	3.04	15.2
TV (weekday)	1	60	4	12:00-16:00	5.58	22.32

Tv(weekend)	1	60	6	06:00-08:00 12:00-16:00	5.58	33.48
Radio(working)	1	30	6	04:00-10:00	2.79	16.74
Injera Mitad	1	2850	0.5	06:00-07:00	265.05	132.5
Mobile charger	2	15	3	13:00-16:00	2.79	8.37
Total						228.6

Power consumption for school is 1.198 kWh/day.

Power consumption for Flour milling is the same in May Shih village which is 200.8 kWh/day

Power consumption for health centers is the same for May Shih Village which is 9.725 kWh/day

The total energy needed for the village is 592 kWh/day