TECHNO-ECONOMIC ANALYSIS OF RENEWABLE ENERGY BASED MICRO GRID FOR RURAL APPLICATIONS

A Thesis Submitted to the
Delhi Technological University
For the Award of Doctor of Philosophy
In

Electrical Engineering

Submitted By:
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2022

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DECLARATION

I, Isaka J. Mwakitalima, a student of Ph.D. hereby declare that the thesis titled **Techno-Economic Analysis of Renewable Energy Based Micro Grid for Rural Applications** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy has not previously formed the basis for the award of any Degree, Diploma Associate ship, fellowship or other similar title or recognition.

Place: Delhi **(Isaka J. Mwakitalima)**

Date: 22/08/2022

CERTIFICATE

On the basis of the declaration submitted by Mr. Isaka J. Mwakitalima, student of Ph.D., we hereby certify that the thesis titled **Techno-Economic Analysis of Renewable Energy Based Micro Grid for Rural Applications** which is submitted to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Doctor of Philosophy is an original contribution with existing knowledge and faithful record of research carried out by him under our guidance and supervision.

To the best of our knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Date: 22/08/2022

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DEDICATION

This work of dissertation is dedicated to my beloved departed parents, my mom **Tausi Anyitike Ntale Mlangala** and my daddy **Jackson Hassan Mwakitalima Mwakinyala**, who supported my scholastic journey since my childhood but did not live longer to witness very important event of accomplishing PhD studies.

Also, the work is dedicated to my loved late paternal grandparents, my grandfather **Hassan Nsaje Mwakitalima** and my grandmother **Batiseba Simbonja Mwakitalima.**

Furthermore, the work is devoted to my precious deceased maternal grandparents, my grandfather **Anyitike Mwamlangala Ntale** and **Limenye Pitala Sibata.**

Moreover, the research is also dedicated to my big mum, the late big mum **Nelusigwe Sampenja** for her love, affection, and care she constantly made to me. I miss you big mum.

The research is also highly dedicated to my all teachers for their unforgettable contribution at different times in the pursuit of academic attainment.

Place: Delhi **(Isaka J. Mwakitalima)**
Date: 22/08/2022

ACKNOWLEDGEMENT

In the very beginning, I humbly thank the Almighty God for the accomplishment of my PhD studies at Delhi Technological University (DTU).

I am immensely indebted to my supervisors, **Prof. Dr. Mohammad Rizwan** and **Prof. Dr. Narendra Kumar**, for their keen support at the whole period of my studies, especially scholastic guidance, academic materials, endurance and lovely care. I am also grateful to the academic society such as academicians, researchers, scientists, technologists, experts, and authors whose references of my research work have been acquired.

I am also thankful to my all friends from the Department of Electrical Engineering of DTU. I am very delighted to mention, in particular, few names of my colleagues: **Mohd Bilal, Astitva Kumar, Bandana Sharma, Priyanka Anand and Ganesh Kumar Jaiswal** for their treasurable support and cooperation in various ways in the whole period of my studies. Their social and educational support is highly recognized. I am also delighted to mention my sincere gratitude to **Deepak Kumar**, **Arpana Singh** and **Rahma Aman** for their cooperation. Specifically, I am also obliged to my friend from the Republic of Kenya Mr. **Issak Abdow Hassan** for our meaningful friendship of supporting each other in innumerable aspects.

I am also appreciative to government of India for rendering me the scholarship through the International Council of Cultural Relations (ICCR). My appreciation is extended to the entire management of DTU, particularly the Department of Electrical Engineering for every support that was given to me. My gratitude is also conveyed to all teaching and non-teaching staffs in the department. I also specifically recognize constant support in the electrical energy utilization laboratory from **Ankit Kumar**, **Vickey Kumar Parsad** and **Manoj Kumar Singh**. I also recognize the support from the office of international affairs (OIA) of DTU. I am pleased to thank the dean of OIA, **Prof. Dr. Vishal Verma**, and to the associate dean of OIA, **Prof. Dr. Roli Purwar** for their assistance. I am also grateful to the government of the United Republic of Tanzania for allowing me to study in one of the reputable universities of the beautiful nation of India. Besides, I have a pleasure to express a lot of thanks to the administration and co-workers of Mbeya University of Science and Technology (MUST), for their cooperation.

Also, I appreciate the office of Mbeya region for giving me the permit of carrying out the research in one of its rural areas, the management of Mbeya District Council Hospital

(MDCH) for helping me during the data collection, the administration of Ifisi hospital in Mbeya city in Tanzania for assisting me in order to get supplementary data which were not available at the new building of MDCH but with related conditions and requirements, and the office of Ikukwa ward. I express my gratitude to all residents of Ikukwa ward who warmly participated in one way or another assisting me during data gathering. I thank them for their kindness and hospitality.

I am glad to give uncountable cheers to my late loved mum **Tausi Anyitike Mlangala** for her affection and unceasing support. Mum, I love and miss you. I am deeply indebted to my dear deceased dad **Jackson Hassan Mwakitalima Mwakinyala** for his endless adoration and care. Dad, I love and miss you. I humbly recognize, in particular, affection, inspiration and assistance from my uncle **Nixon Hassan Mwakitalima Mwakinyala, (**and his family as well) who backed me up in the pursuit of scholastic attainment. Dear uncle, I am very thankful.

I am pleased giving many thanks to my lovely wife **Juliana Mpuli Kanyelile** who has been taking care of my children and managing family affairs during my absence. I love you dear, thank you for your encouragement. I would like to say my lovely thanks to dear sons **Tumsifu Isaka J. Mwakitalima** & **Mark Isaka J. Mwakitalima** and to my little girl **Tulinuntwa Isaka J. Mwakitalima** who have actually missed out their parental care. Generally but respectively, I am also happy to recognize the support of numerous ways from my dear brothers, sisters, aunts, uncles, and everyone. Our strong togetherness is our victory. As the matter of fact it is impossible to list all the names of my friends who assisted me in sundry ways. Frankly speaking, the full list of my all friends is accommodated in my heart for my appreciation. Finally but not the least, I would also like to remember my departed neighbour and who was also a friend Mr **Simon Bukuku** who lost his life suddenly after accident before seeing the completion of my studies. He greatly supported me for all ways during the very beginning of my research.

Place: Delhi **(Isaka J. Mwakitalima)**
Date: 22/08/2021

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LIST OF SYMBOLS, ABBREVIATIONS AND NOMENCLATURE

List of Acronyms

AAP	Aggregated Annualized Price (\$/year)
AIP	Annualized Investment Price (\$)
ASP	Annualized Spare Price (\$/year)
$LEPP^{maxi}$	Maximum Loss of Electrical Power Probability
$\mathbf{c_{OPR}}$	Operating Charge
$\overrightarrow{\mu_1}$ and $\overrightarrow{\mu_2}$	Coefficient Vectors of Targeted Victim
$\overrightarrow{R_{1,}}\,\overrightarrow{R_2}$	Arbitrary Vectors in the Range of 0 to 1.
$T_{C_{Ref}}$	Reference Temperature (° C)
H_{GEB}	Lifetime in hours of biogas fuelled system (Years)
η_{btt}	Efficiency of Battery (%)
$\acute{\eta}_{GEB}$	Conversion Efficiency of Biogas Energy System (%)
$\acute{\eta}_{PC}$	Power Conditioning Efficiency (Equals to 1 with application of MPPT)
$\acute{\eta}_{PVE}$	Solar PV Output Efficiency (%)
$\acute{\eta}_{r}$	Reference Module Efficiency (%)
A_{PVP}	Area of the Panel (m^2)
A_{PV}^{mx}	Maximum area of Panel (m^2)
CV_{GEB}	Calorific Value of Biogas Which is Equivalent to 4,700 kilocalories/ Kg
E_{Annual}	Total Energy Produced per Annum (kWh/Year)
E_{DEM}	Energy demand (kW)
E_G	Energy Band Gap
E_{GEB}	Power produced by biogas generator (kW)
E_{HDT}	Power produced by Hydro Power Technology (kW)
E_{INV} and η_{INV}	Input power (kW) and the efficiency of inverter (%) respectively.
E_{cgg}	Charging Capacity of the Batteries (AH)
E_{dgg}	Discharging Capacity of the Batteries (AH)
E_{global}	Global Solar Irradiance (kWh/m^2/year)
G best	Global best value
I_{RR}	Reverse Saturation Current (Ampere)
I_{STC}	Irradiance Solar Radiation (1 kWh/m^2) under STC,
I_T	Total solar irradiation (1 kWh/m^2)
Pe_{wave}	Power produced by wave (J/S)
$P_{ghybrid}$	Total Power Generated from Hybrid Micro Grid System
P_{tide}	Produced Power by Tide (J/S)
$\rho\ _{air}$	Air Density (kg/m3)
ρ_{water}	Water Density (kg/m3)

C1 and C2	Constants Related to Velocity
Cp	Wind Power Coefficient (Belts limit)
CRF	Capital Recovery Factor
f (V)	Wind Velocity Probability Density Function
I_{SC}	Short Circuit Current (Ampere)
K	Constant of Boltzmann
Max iter	Maximum Number of Iterations
N_{MHT}	Maximum Number of Water Turbine
Pbest	Personal best value
P_{MHPS}	Overall Power Created by a Micro Hydropower System (kW)
P_{MHT}	Estimated Power Generated for a Hydro Turbine Unit (kW)
q	Electron Charge (1.6×10^{-9} C),
Q (t)	Water Flow Rate (kg/m^3) at time t (s)
Q_{Mn}	Minimum Flow Rate (kg/m^3) Below Which Electricity Generation Stops
r1 and r2	Arbitrary parameters for respectively exploitation and exploration coefficients (Range of 0 to 1
Ta	Ambient Temperature (º C)
Tc	Temperature Coefficient/ º C
T_{OPD}	Operating time in hours per day
V_{OC}	Open Circuit Voltage (Volts)
W_max	Maximum weight of inertia
W_mi	Minimum weight of inertia
YEG	Energy generation in kWh with respect to a given wind velocity
ω	Rotational velocity (rad/s)
DA	Number of days of battery bank autonomy
NOCT	Nominal operating cell temperature (º C)
α	Alpha
β	Beta
δ	Delta
λ	Wavelength
ω	Omega

List of Abbreviations

AC	Alternating current
AH	Ampere Hour
AI	Artificial Intelligence
ESS	Energy Storage System
DER	Distributed Energy Resources
DGS	Distributed Generation Sources
ESS	Energy Storage System
FC	Fuel Cell

GWO	Grey Wolf Optimization
HOMER	Hybrid Optimization of Multiple Electric Renewables
HRESS	Hybrid Renewable Energy Supply System
MCG	Micro Grid
MNG	Mini Grid
O&M	Operation & Maintenance
PSO	Particle Swarm Optimization
RES	Renewable Energy Sources
SOFC	Solid Oxide Fuel Cell
SER	Series
SPV	Solar Photovoltaic
STC	Standard Testing Conditions
ToU	Time of Use
SWTES	Small Wind Electric System
WT	Wind Turbine
AS	Amorphous Silicon
BB	Battery Bank
BES	Biogas Extension Service
BGE	Breakeven Grid Extension
CAMARTEC	Centre for Agricultural Mechanization and Rural Technology
CF	Capacity Factor
CSP	Concentrated Solar Power
DC	Direct Current
DG	Diesel generator
DOD	Depth of Discharge
DPGE	Distributed power generation
DPP	Diesel Power Plants
EAC	East African Community
EDL	Economic Distance Limit
EGS	Enhanced Geothermal Systems

EIA	Environment Impact Assessment
EJ	Exajoule (1 EJ = 10^{18} J)
EWURA	Energy and Water Utilities Regulatory Authority
FESS	Flywheel Energy Storage System
FiT	Feed in Tariff
FRG	Federal Republic of Germany
GCMs	
GDP	Gross Domestic Product
GER	Geothermal Energy Resource
GHG	Greenhouse gases
GHRESS	Grid-connected Hybrid Renewable Supply System
GWO-PSOHD	Grey Wolf Optimization and Particle Swarm Optimization Hybrid
HAWT	Horizontal Axis Wind Turbine
HMCG	Hybrid Micro Grid
HPP	Hydro Power Pants
IEA	International Energy Agency
IEC	International Energy Charter
IHC	Ikukwa Health Centre
JNHPP	Julius Nyerere Hydro Power Project
LCC	Life Cycle Cost
LEPP	Loss of Electrical Power Probability
LPG	Liquefied Petroleum Gas
LV	Low Voltage
MCFC	Molten Carbonate Fuel Cells
MDCH	Mbeya District Council Hospital
MHPS	Micro/Mini Hydro Turbine System
MHT	Micro Hydro Turbine
MMS	Mbeya Meteorological Station
MOE	Ministry of Energy
MSMSS	Multi-Source Multi-Storage System
NASA	National Aeronautics and Space Administration
NEMC	National Environmental Management Council
NG	Natural Gas
NGO	Non-Government Organization
NGPP	Natural Gas Power Plant

NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
ORC	Organic Rankine Cycle
OTEC	Ocean Thermal Energy Converters
PEL	Parallel
PHESS	Pumped Hydro Energy Storage System
REA	Rural Energy Authority
REF	Rural Energy Fund
SCESS	Super-Capacitors Energy Storage System
SEI	Specified Exergy Index
SER	Specific Exergy Rate
SHRESS	Standalone Hybrid Renewable Supply System
SHS	Small House System
SOC	State of Charge
SOFC	Solid Oxide Fuel Cells
SPV	Solar photovoltaic
SRES	Sustainable and Renewable Energy Resources
SSA	Sub Saharan Africa
SSE	Surface Meteorology and Solar Energy
SSP	
STT	Solar Thermal Technologies
SWH	Solar Water Heating
TANESCO	Tanzania Electricity Supply Company
TMA	Tanzania Meteorological Agency
TPDC	Tanzania Petroleum Development Corporation
TCF	Trillion Cubic Feet
TEG	Thermo Electric Generators
TGDC	Tanzania Geothermal Development Company
URT	United Republic of Tanzania
USD	United States Dollar
VAWT	Vertical Axis Wind Turbine
VEO	Village Executive Officer
WB	World Bank
WEC	Wave Energy Converter
WEO	Ward Executive Office

WPCS	Wind Power Conversion System
ZECO	Zanzibar Electricity Corporation

ABSTRACT

The need for power supply from the main grid is rising drastically as the investment in economic activities and population grow rapidly, as does the improvement of comfort level and power consumption required by contemporary home appliances. Global warming and greenhouse gas (GHG) emissions have negative impacts due to the use of fossil fuel power plants. These are the main challenges which have given pressure in using sustainable and renewable energy resources (SRES) for power generation. Moreover, the world's energy sector is confronted with growing issues as a result of increased energy demand, efficiency, supply fluctuations and energy demand dynamics, and a shortage of analyses essential for appropriate energy management.

Incorporation of artificial intelligent solutions into power systems, possess the high potential to enhance power efficiency, cost savings, and user comfort. As a result, it is imperative to create intelligent optimization-based algorithms for use in various renewable energy systems. In this study energy systems are mainly hybrid solar- based micro-grid systems. In particular, this study investigates the potential of hybrid biogas fuelled systems for generating electricity for commercial use in Tanzanian environment and potential of non-perennial tributary for electricity generation particularly in areas with a long standing period of time and extensive high rainfall for expanding the potential of hydro energy resource.

This research work presents the techno-economic feasibility analysis of a standalone solar photovoltaic (SPV) system coupled with a battery bank that is expected to offer power to a typical rural residence at Simboya village using hybrid optimization multiple energy renewables (HOMER) and particle swarm optimization (PSO) platforms. HOMER is used to carry out techno-economic viability analysis of small wind turbine electric system (SWTES) for electrical water and power supply for peasant’s residence at Simboya village, it describes the techno-economic feasibility assessment of a hybrid SPV/biogas generator/battery system optimized by HOMER pro and the grey wolf optimization (GWO) platforms to supply power to Simboya village, also it covers the techno-economic evaluation of the SPV-hydro-biogas-battery bank system which is expected to deliver power to same village, it presents the techno-economic study of the SPV/Small hydro/Battery energy system configuration predicted to supply electricity to Ikukwa village utilizing HOMER, PSO , GWO, and GWO-PSO hybrid platforms. The key findings of this research work are summarized as follows: Findings by HOMER platform, daily electricity consumption and peak power output of the

residential house for the proposed rural site is 0.16kWh/day and 0.18kW, respectively. Total net present cost (NPC) of standalone SPV system (first scenario) and diesel generator (DG) set (second scenario) are $ 2089 and $ 19 488, respectively. Optimization results by HOMER software and the PSO technique for the aforesaid configurations (scenarios) are also compared. Optimization results of scenario 1 (SPV system) indicate the reduction of total NPC in the PSO technique equivalent to 69.33% while results of scenario 2 (DG) show the decline in total NPC in the PSO technique equals to 69.31%. Scaled peak power and energy consumption during rainy season are 1.48 KW and 11.26 kWh / day respectively. Total NPC for SWTES is $ 106 273. 80 and levelized cost of energy (LCOE) is estimated to be $ 1.58/ kWh. The cost for batteries is $ 77 892. 96 (73.3%) being higher than the cost for wind turbine (WT) which is 18 369. 80 (17.3%). The cost for converter is $ 6713.11(6.3%).
In optimization by HOMER, the optimal configuration of SPV/biogas generator/battery system components are 40 kW SPV, 25 kW biogas generator, 144 Generic 1kWh Li-ion batteries, four in series with 36 strings of system bus voltage 24V and 40 kW converter with a dispatch strategy of cycle charging. Total NPC, investment cost, LCOE for the off-grid hybrid renewable energy supply system (HRESS) is $106,383.50, $ 78500 and $ 0.1109/kWh respectively. The analysis of the optimized system by GWO method has shown that over-all NPC and LCOE are $ 85, 106 A and $ 0.0887/kWh respectively. The use of AI optimization (GWO) technique has further reduced the financial metrics of power generation up to around 20 % when compared with HOMER. Moreover, techno-economic analysis is carried out for off-grid hybrid SPV-hydro- biogas-battery bank system for delivering power supply to Simboya village. HOMER platform is used for simulation purposes. The penetration levels for hydro and SPV energy sources are 470 % and 90.1 %, respectively. The efficiency of biogas generator is estimated to be 31.0 %. The optimal design of off grid hybrid system consists of 10 kW of biogas, 30 kW of SPV, 85.1 kW of hydro, 48 batteries and 20 kW of converter. Total NPC and LCOE for hybrid solar PV-hydro- biogas-battery bank system & DG are $ 77861.88. Optimal results of SPV/Hydro/battery hybrid micro grid system based on the lowest NPC via HOMER , PSO, GWO, and GWO-PSO hybrid technique platforms are $ 141, 397.76, $ 95,167.21, $ 92,472.82, and $ 91, 854.10, respectively. Optimization results of same configuration in terms of LCOE via HOMER, PSO, GWO, and GWO-PSO hybrid technique platforms are $ 0.1818/ kWh, $ 0.1185 kWh, $ 0.1182/ kWh, and $ 0.1181/ kWh, respectively. Conclusively, renewable energy based systems are cost effective, sustainable and ecologically friendly. Optimization using AI algorithms yield significant results in minimal generation costs.

CHAPTER 1

INTRODUCTION

1.0 GENERAL

This chapter of an introduction starts by giving a brief discussion of general background of energy including the conventional energy resources in the today's electricity industry. It also discusses the importance of utilizing renewable energy resources for addressing the high shortage of energy particularly in developing countries including Tanzania. In addition, this cha chapter provides the benefits provided by renewable energy resources to the environment. Global and Tanzanian energy scenarios are also described. The main goal and specific objectives of the research are presented. It also provides an outline of the techno-economic feasibility analyses of the proposed individual renewable energy based systems of dissimilar configurations (Single and hybrid power sources) for multiple energy services of selected rural site in Tanzania. The presentation of thesis structure is provided at the end of this chapter.

1.1 EXPLANATION OF ENERGY

Energy plays a great role in our daily life. Without energy, we would be unable to maintain our current way of living (Xia *et al.*, 2022). The provision of energy, or more accurately, related energy services (such as heated dwelling spaces, mobility, and information), involves a wide range of environmental repercussions that the 21st century society is becoming less tolerant of (Strielkowski *et al.*, 2022). This is why the "energy issue" in combination with the underpinning "environmental problem" remains a hot subject in energy engineering as well as environmental and energy policies around the world (Hossain, 2016).

1.2 TERMINOLOGIES RELATED TO ENERGY

Energy, as per Max Planck, is defined as a system's ability to induce external action. Thermal, mechanical energy (potential/kinetic energy), electric, and nuclear energy, chemical energy, and solar energy are all types of energy that are classified in this way (Kaltschmitt., 2007). The ability to accomplish work is observable in practical energy equipment as force, heat, and light. Chemical, nuclear, and solar energy, as well as other kinds of energy, can only be used to accomplish work if they are converted into thermal and/or mechanical energy (Osterhage, 2022).

Energy carrier (hence a carrier of the above-described energy) refers to a substance that can be utilized to generate usable energy either directly or indirectly through one or more conversion processes (Stognief., 2022). Energy carriers are categorized as primary, secondary, or final energy carriers based on the degree of conversion (Kaltschmitt, Streicher et al. 2007). The total energy of the carriers is made up of three components: basic energy, secondary energy, and final energy. Following are the definitions in the context of energy (Kaltschmitt *et al*., 2007):

- The meaning of primary energy refers to the energy content of the energy carriers and the primary energy flows. Primary energy carriers refer to materials prior to any technical transformations. Secondary energy or secondary energy carriers can be created directly or indirectly from primary energy carriers (e.g., hard coal, lignite, crude oil, and biomass).or from primary energy (for instance, wind power, solar insolation) (Kaltschmitt *et al*., 2007).
- Secondary energy carriers are energy carriers that are formed directly or indirectly from main or other secondary energy carriers (for instance heating gasoline, rape oil, oil, electrical energy), where the of meaning secondary energy refers to the total energy of the secondary energy carrier and the associated energy flow. This main energy processing is vulnerable to transformation and delivery losses. Secondary energies and secondary energy carriers are accessible for customers to transform into other secondary or last energy carriers or energies. (Kaltschmitt *et al.*, 2007)

- Final energy and final energy carrier are energy streams that are directly utilized by the end customer (for example light fuel oil in the house owner's oil tank, saw dusts in front of the ignition oven, district warming-up at the building substation). They are the outcome of secondary and maybe primary energy carriers or energies less transformation and distribution losses, self-consumption of the conversion system, and non-energetic consumption. They are ready to be converted into useful energy (Kaltschmitt *et al.*, 2007)
- The energy obtained by the customer after the conversion phase to meet the corresponding energy services (space warming up, food preparation, transportation, information) is referred to as useful energy. It is derived from the final energy carrier or final energy, which has been decreased by the losses of this final conversion (for example losses of wood piece fired stove to produce heat, losses due to the heat dissipation to produce light by an electric bulb) (Kaltschmitt *et al*., 2007).

1.3 ENERGY TRANSITION PROCESS

The total amount of energy available to human beings is referred to as the energy basis. It is made up of the energy from exhaustible energy resources and renewable) energy sources (Kaltschmitt *et al.*, 2007). In the light of the conservation law of energy, the energy is always fixed. Energy can be converted from one to another type of energy. There are various kinds of energy such as electrical, mechanical, chemical; light and thermal energies (Xu *et al.*, 2012). For instance, Figure 1.1 indicates energy transformation process.

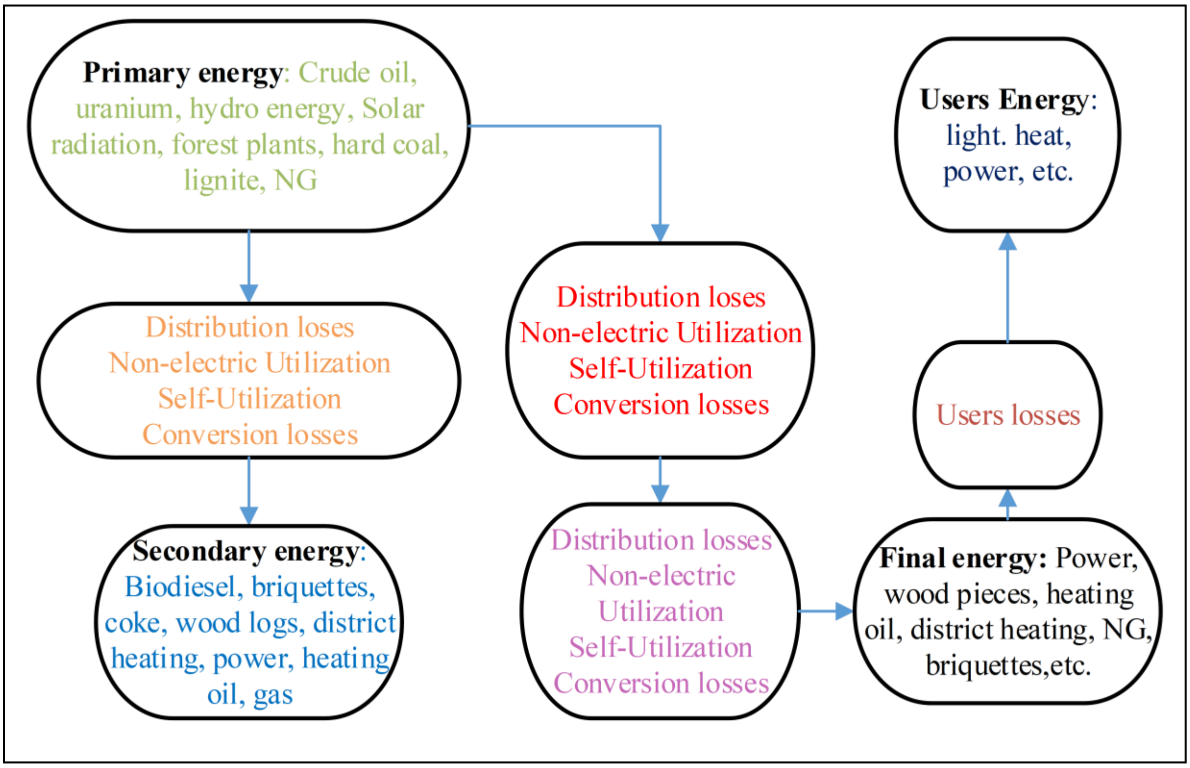


Figure 1.1. Energy transformation process.

1.4 CATEGORIES OF ENERGY RESOURCES

Energy resources are categorized into main energy resources namely conventional (Non-renewable) and non-conventional (Renewable) energy resources (Vivek *et al.*, 2021). Based on these categories of resources electricity can be generated via mechanical devices such as engines and turbines (Hulio *et al.*, 2022). Figure 1.2 indicates the principal categories of energy resource

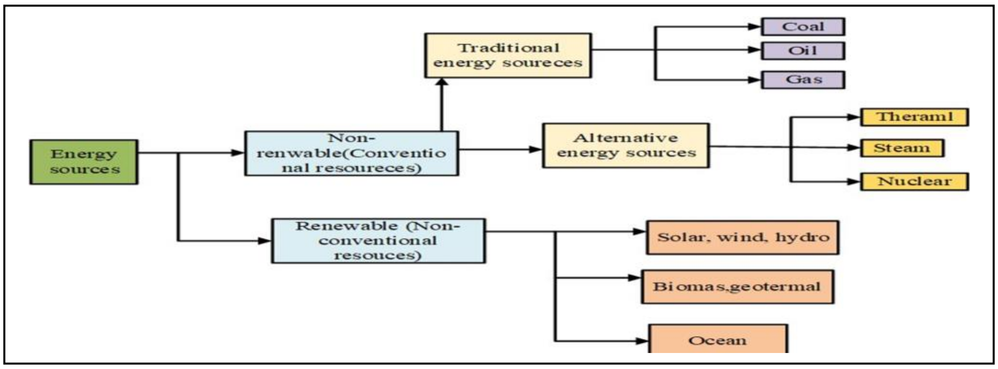


Figure 1.2. Categories of energy resources

1.4.1 Non-Renewable (Conventional) Energy Resources

Non-renewable (Conventional) energy resources are limited in quantity and cannot be restocked. They are made from crude oil, coal, uranium, and natural gas (Sharma, 2022)**.** In other words, non-renewable or conventional energy resource produces electricity without being replenished naturally subsequent to the utilization of power generation (Asif *et al.,* 2022). These resources are finite and their utilization in power production pollutes the environment leading to the effects of global warming. Conventional energy sources are farther categorized as alternative and primary energy resources (Alrwashdeh, 2022). A list of primary energy sources includes oil, natural gas, and coal. Alternative energy sources are derived from primary energy sources. A list of alternative energy includes nuclear, steam and thermal sources (Alrwashdeh 2022, Sharma, 2022).

1.4.2 Renewable (Non- Conventional) Energy Resources

Renewable (Non-Conventional) energy is defined as energy derived from renewable resources that replenish themselves on a human timescale such as sunshine, wind, hydro, tides, waves, and geothermal heat (Dasanayaka et al., 2022). The non-conventional is frequently used to generate electricity, heat and cool air and water, power transportation, and provide remote energy services. The provision of final or useful energy utilizing non-conventional energies is based on energy flows caused by planet movement and gravitation, that is, tidal energy, heat absorbed and emitted by the earth, that is, and geothermal energy and, in particular, energy emitted by the sun, that is, solar radiation(Zahedi *et al*., 2022). Thus, there is a wide range of non-conventional energies based on energy density, differences in available sources of energy, intermediate or ultimate energy carriers, and final energy to be delivered. As it has been explained above renewable energy can largely be utilized to solve the energy shortage especially in rural and remote areas of the developing countries (Dasanayaka *et al*., 2022). In contrary with the conventional (Traditional) energy resources, non-conventional energy has remarkable potential to reduce environmental, atmospheric, and atmospheric impurity challenges, as well as reliability, energy security, and availability in most parts of the world (Dasanayaka *et al*., 2022). Indeed, renewable energy supplies are the appropriate alternative solution to global environmental challenges caused by fossil fuels.

1.4.3 Highlights on the Use of Renewable Energy Sources and Their Environmental Benefits

As described in the foregoing sections, renewable energy is defined as energy derived from renewable resources that replenish themselves on a human timescale such as wind, sunshine, hydro, tides, waves, and geothermal heat (Dasanayaka *et al*., 2022). Renewable energy source is frequently used to generate electricity, heat and cool air and water, power transportation, and provide remote energy services. Following is a brief description and presentation of environmental benefits of an individual renewable energy resource:

1.3.3. 1 Solar energy resource

Solar energy is the radiant light and heat emitted by the Sun that is captured utilizing a variety of constantly progressing technologies like photovoltaic (PV), solar heating, synthetic photo-synthesis, molten salt power plants, solar architecture, solar thermal energy (Chougule *et al*., 2022). It is a significant source of renewable energy, and its methods are roughly classified as either passive solar or active solar, depending on how they capture, distribute, or convert solar radiation into solar power. In order to harness the energy, active solar approaches such as solar PV systems, CSP (concentrated solar power) and SWH (Solar water heating) are used (Zhang *et al*., 2022). Orienting a structure to the Sun, selecting materials with favourable light-dispersing and thermal mass qualities, and designing rooms that naturally circulate air are all examples of passive solar approaches. Solar power system harnesses the sun's clean energy. The primary advantage of solar energy to environment is that it produces no pollution and is one of the cleanest forms of electricity. Also, solar energy reduces the reliance on collective fossil fuels (Zhang *et al.*, 2022). Though, it can possibly have indirect detrimental influences on the environment since solar photovoltaic (PV) cells, which convert sunlight into electricity, include some harmful elements and chemicals. However, the harmful impact is very minor. The main benefit of solar energy is that it does not yield any pollutants and is one of the cleanest sources of energy. Also, reduces the dependence on the fossil fuels (Zahedi *et al.*, 2022). Though, solar energy possibly can have indirect negative impacts on the environment as some toxic materials and chemicals are used to make the photovoltaic (PV) cells that convert sunlight into electricity. But this negative effect is quite negligible (Zahedi *et al.*, 2022). Application of solar energy is constantly gaining popularity worldwide. Figure 1.3 indicates the Global growth of solar energy application (Pandey *et al.*, 2022).

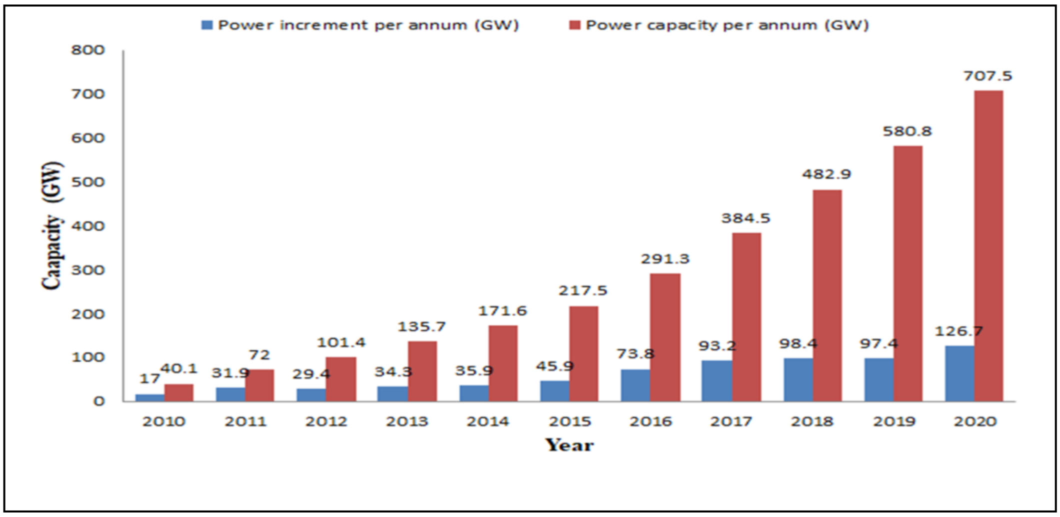


Figure 1.3. Global growth of solar energy application since 2009 to 2020

1.4.3. 2 Hydro energy resource

Flowing water generates energy, which can be caught and converted to power. The most popular type of hydro- electric power station stores water in a reservoir behind a dam on a river. When water is released from the reservoir, it flows into a turbine, spinning it and activating a generator, which produces power (Muratoglu and Demir, 2022). Globally, SHP represents 1.5% of total electricity installed capacity, 4.5% of renewable energy installed capacity, and 7.5% of hydropower capacity (Kishore *et al*., 2021). Figure 1.4 shows the year-wise growth in MHPS's installed capacity and existing potential worldwide. Merits of hydropower technology are: (Siam *et al*., 2022) (i) Capability of traditional hydroelectric dams with ponds to retain water at cheap cost for later dispatch as high value clean energy is their primary advantage. They require just few employees on site during regular operation and lower labour costs (ii) Because hydroelectric dams do not use fossil fuel, power generation does not emit any CO2 (iii) Despite the fact that reservoirs emit some methane on a yearly basis, hydro has the lowest lifecycle greenhouse gas emissions for power generation when compared to fossil fuels delivering the same amount of energy (iv) Reservoirs built by hydroelectric systems are frequently used for water sports and have become tourist attractions in their own right (v) Reservoir aquaculture is common in various countries. Irrigation dams with many reservoirs provide agriculture with a reasonably steady water supply. Application of hydro power technology is mature and is widely used to generate electricity worldwide (Fan *et al*., 2022).

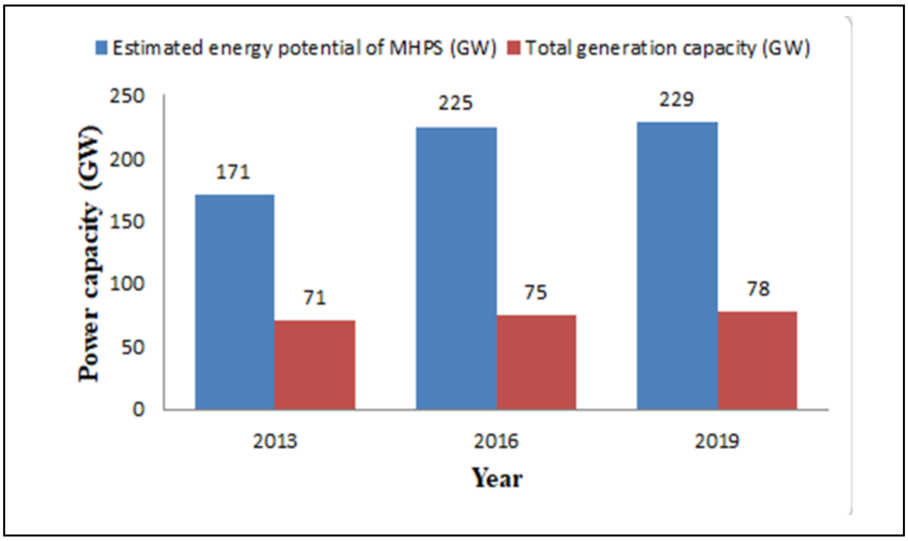


Figure 1.4. Year-wise growth in MHPS's installed capacity and existing potential worldwide.

1.4.3. 3 Wind energy resource

Wind is a clean energy source with almost no polluting qualities or adverse effects. Wind power is a type of solar energy (Bhandari, Poudel et al. 2014). It refers to the process of generating power from wind. Wind turbines transform the energy from the wind into prime mover, which is then converted into electricity by a generator. Wind energy can be utilized for more than only generating power; it may also be utilized to charge batteries, pump water, and grind grain. Figure 1.5 indicates the global growth of wind. It does not pollute the air in the same way that power stations that use fossil fuels like coal or natural gas do. Figure 1.5 indicates global installed capacity of wind energy .Advantages of wind turbine are (Letcher 2017) (i) Wind turbine does not emit harmful pollutants into the atmosphere, such as those that cause asthma or acid rain, nor does it emit greenhouse gases (ii) Unlike the traditional electricity sources, wind power does not require the use of water. Water is used to cool nuclear, coal, and gas-fired power plants, for example (iii) Wind energy exists locally. (iv)Wind energy is limitless (infinite) and as far as the sun does shine and the wind blows, the energy generated can be used to power the grid (v) Wind energy is inexpensive. It is one of the most affordable renewable energy sources available at the moment (vi) Implementation of wind energy can create jobs locally.

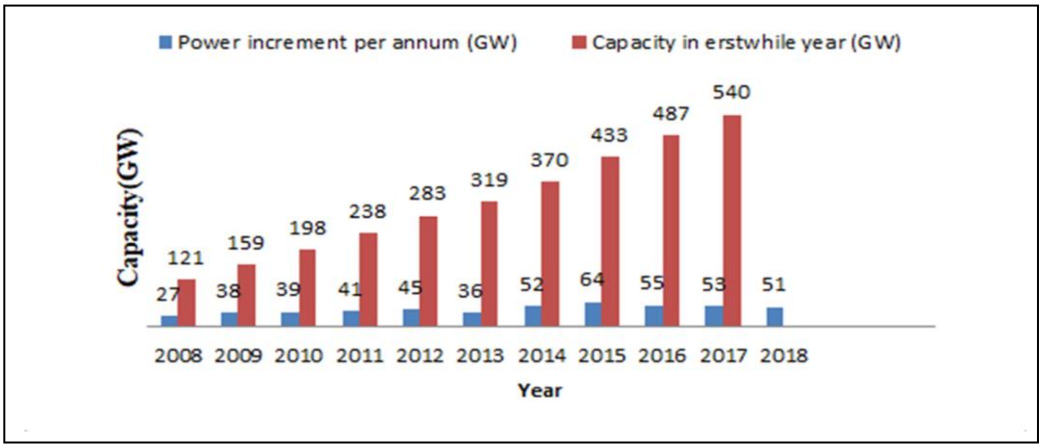


Figure 1.5. Global installed capacity of wind energy

1.4.3. 4 Biomass energy resource

Biomass is an organic material derived from animals and plants that is a renewable energy source. It is made up of sun-stored energy. This energy in biomass is converted to heat when it is burned (Adegoke *et al.*, 2022). The process of photosynthesis, which occurs when trees and plants develop, takes energy from the sun to transform CO2 into carbohydrates (cellulose, sugars, and starches). Carbohydrates are organic molecules found in biomass. When plants die, the degradation process releases the energy held in carbohydrates and emits CO2 into the environment (Anyogu *et al.*, 2022). Since the growth of new plants and trees replaces the supply, biomass, is therefore, a renewable energy source (Anyogu *et al.*, 2022). Humankind's original fuel source was biomass. The most evident ecological gains of biomass is the lowering the acid rain and air pollution caused by the substitution of biomass for fossil fuels. Some merits of biomass are such as Biomass energy is produced from organic material, such as plant or animal waste, and these resources are never depleted, CO2 released by fossil fuels can be captured by biomass, biomass has low-cost and widely available energy source, landfills (wastes of biomass) can be removed into useful thing, reduces over-reliance on fossil fuels, and so on (Anyogu *et al.*, 2022).

1.4.3. 5 Geothermal energy resource

Geothermal energy refers to the seat energy that is produced and retained in the Earth. It is both sustainable and clean, and it can be found in the rock and liquids beneath the Earth's surface (Islamovich, 2022). It is available from the lower deep surface to several meters below the surface, and even deeper to the exceptionally hot igneous materials known as magma. The environmental implications of geothermal energy are determined by how it is used or transformed to usable energy. Direct applications and geothermal energy pumps have essentially minimal environmental impact (Rybach, 2022). Some merits of geothermal energy source are such as geo-thermal power station has a very low carbon footprint (Anyogu *et al.*, 2022). The CO2 which can be emitted by geothermal plants is approximately one-eighth of that emitted by an equivalent coal power station, The plant's power output can be forecast and is not susceptible in comparison with variations as solar or wind (stable and dispatchable), geothermal reservoirs are refilled naturally, there's no requirement for fuel, a little plot of land is required for the plant's construction, in some locations, geothermal power is cost-competitive, most sites have some degree of geothermal energy.(accessibility), etc. Global geothermal installed capacity has increased from roughly 9992 MW in 2010 to approximately 13,931 MW in 2019 (Haghighi et al., 2021).

1.4.3. 6 Wave energy resource

The conveyance of energy by water waves and the harnessing of that energy to conduct beneficial work such as electric generation, water desalination, or reservoir pumping are all examples of wave power. WEC (wave energy converter) is a mechanism that uses wave power to generate electricity (Prasad *et al.*, 2022). The diurnal flow of tidal energy and the sustained gravity gradient of ocean circulation are not the same as wave power. Although wave electricity production is not now widely used as a commercial technology, attempts to use it have been made since 1890 (Rupesh *et al.*, 2021). Merits of wave energy source are (Rupesh *et al.*, 2021) : Wave energy is not exhaustive (do not deplete), wave energy produces no hazardous consequences such as gas, trash, or pollution; wave energy can be directly converted into electricity; it is plenty and readily available, it is predictable, It is not destructive to the land (there is no land damage).

1.4.3. 7 Tidal energy resource

This is a type of hydropower that uses a generator to turn the power of the tidal currents into electric power or other usable forms of power (Curto *et al.*, 2021). Tidal energy has the potential to generate future electricity, because tides are more predictable than wind and solar radiation (Chowdhury *et al.*, 2021). Tidal power is the only technique that makes use of the energy contained in the orbital properties of the earth-moon arrangement and, to a lesser extent, the Earth-Sun system. Since the earth's tides are fundamentally caused by the gravitational attraction of the moon and sun, as well as the rotation of the Earth, tidal power is virtually infinite and is categorized as a renewable energy resource. Tidal power is a renewable of power that does not produce the greenhouse gases or acidic rain derived from fossil fuel during the generation of electricity (Dassanayake *et al.*, 2021). Some of the merits are (Anyogu *et al.*, 2022): It is an infinite source of energy, it is ecologically friendly and does not emit greenhouse gases, the life of a tidal energy power station is very extensive, tidal energy does not require any type of fuel to run, the power content of tidal energy is comparatively higher than other renewable energy sources, and the efficiency of tidal energy is far higher than coal, solar, or wind energy (approximated efficiency is around 80 percent).

1.5 BRIEF EXPLANATION OF ENERGY SCENARIOS

This section briefly explains the global energy scenario, Africa continent energy scenario, and Tanzanian energy scenario, energy scenario at designated place of study in Tanzania, why solar energy-based systems in this study, main goal and specific objectives, conclusion and adoption of renewable energy resources at the area of study, and research approach & contributions.

1.5.1 Global Energy Scenario

The power sector, being the greatest source of anthropogenic CO2 emissions, accounting for 37 percent of total of global CO2 discharges due to man-made activities in 2019 related to 30% in 1990, and it plays a large role in global carbon commitment and climate change mitigation (Qin *et al.*, 2022). Global fossil fuel power generation increased at a 3.0 percent annual average pace from 7,609 TWh in 1990 to 17,642 TWh in 2019, driven by population growth and economic expansion (Qin *et al.*, 2022). The CO2 emissions in the globe from the power sector have so increased substantially with the rise in demand for generating electricity in recent decades, with many emerging nations experiencing faster growth rates in electricity output and CO2 emissions from power plants (Qin *et al.*, 2022). For instance, in the period starting from 1990 to 2019, it is estimated that the amount of recognized low-efficiency coal -fired power capacity reduced to 4.3 percent in the USA and 0.6 percent in Europe, with 2.1 percent and 13.2 percent thermal efficiency gains, respectively. In contrary, emissions of CO2 in India, China, and plus the rest of the world continue to rise since rising electricity demand is primarily supplied by constructing carbon-intensive but inefficient coal generating generation (Qin *et al.*, 2022). However, with increased electrification and the replacement of direct fuel use in power consuming sectors with electricity, the expansion of power generation is projected to continue. The accelerated dissociation of international power generation demand from CO2emissions is an essential step in the next decades to meet the Paris Agreement goal of limiting temperature rise to well below 2 degrees Celsius over pre-industrial levels and aiming for 1.5 degrees Celsius.

Currently, fossil fuels account for 82 percent of global energy consumption and produce to two-thirds of man-made greenhouse gas emissions. Precipitation variability, temperature, and the frequency of extreme weather events are all predicted to rise as the climate continues to change (Qin *et al.*, 2022). Climatic variation, along with wealth and population increase, is predicted to influence future global energy demand, which may raise the global emissions derived from GHG's and so cause more climate change (Qin et *al.*, 2022). Ascertaining this weather energy consumption has crucial implications for discussions about the proper transition to low emission power systems and other types of greenhouse gas mitigation efforts to prevent climate change, such as the Paris Agreement's 2 °C limit (Zhang *et al.* 2022).

It has been predicted that climate change would increase global total energy consumption between 2016 and 2095, but at varying rates in poor and rich and poor nations (Zhang *et al*., 2022). For example, under SSP5 with income and population growth, global total energy use in 2095 is anticipated to increase by 24.0 percent on average (Zhang, *et al*., 2022). However, there are significant disparities between poor and rich countries, with poor countries experiencing almost three times the growth under SSP5 (36.8 percent, as opposed to 12.2 percent). In reality, 79.8 percent of countries have increased total energy use, with the Middle East, Africa, South America and South Asia, are exhibiting the greatest growth (Zhang, *et al.* 2022). Some Sub-Saharan African nations have started struggling with health and poverty challenges. Policymakers must design and implement efficient and effective adaptability policies to address both climate change and development challenges concurrently (Zhang *et al., 2*022).

1.5.2 Africa Continent Energy Scenario

Access to clean energy is vital to the functioning of a sustainable planet. Policymakers believe that universal access to affordable, reliable, and clean energy can help eradicate poverty, improve health, achieve gender equality, and enable communities to adapt to climate change and food security issues (Li *et al.*, 2021). Clean and reliable energy can generate jobs, improve transportation, and help create more sustainable, all-encompassing (inclusive), and resilient societies. Accordingly, the provision of affordable and clean energy is one of the 17 goals (worldwide) adopted by the UN (United Nations) general assembly in 2015 (Li, *et* *al.*, 2021). However, progress toward this goal has been unequal throughout African economies in recent decades (Borowski, 2021).

African continent is very resourceful in terms of energy resources. Nevertheless, the continent has high energy demand in both urban and rural areas due to the fast growth of population, industrialization, globalization, urbanization, mining, tourism industry, unreliable power grid due to outdated infrastructures, and investment in new infrastructures (Ayinde, 2019). As it has been enlightened in the foregoing explanation, in Northern parts of Africa (Arabic countries) the energy situation is far better than SSA states (Access ranges from 99% to 100 %). The power sector in SSA region is facing major challenges, for instance, the current high birth rates (rapid growth population), meaning that the population at least from 590 to 600 million people now fall into the category of energy poverty (i.e., lack of access to electricity), and it is expected that 530 million people will still lack access to energy by 2030 (Borowski, 2021). Figure 1.21 indicates typical trend evolution of the electricity demand (TWh) among the scenarios at the African level the period 2015-2030 (Borowski, 2021). Furthermore, the issue for the energy industry is the growth of a sector with a total installed capacity of less than 100 GW (Borowski, 2021).

Moreover, the majority of the population in Northern parts of Africa has access to energy and clean cooking methods. This contrasts sharply with the scenario in SSA region, 43 percent of the population lacks access to electricity, and at least 700 million people cook over open fires fueled by solid biomass (Dalla Longa and van der Zwaan, 2021). Sub-Saharan Africa encompasses all of Africa, with the exception of the five primarily Arab governments of Algeria, Morocco, Egypt, Tunisia, and Libya plus Sudan. The populations from these countries have access to electricity ranging from 99 to 100% access to electricity *(Pappis et al.*, 2022). Sub-Saharan Africa comprises 49 of Africa's 54 countries.

Both South Africa and Nigeria consume 40 % of total consumption in the region largely for residential premises (Mas’ud *et al.*, 2016). Similarly, in 2019 the WB (World Bank) estimated that 840 million individuals are still living without access to electricity SSA nations being the most disadvantaged region. The Covid-19 pandemic has resulted in greater downgrading of this population, and according to a recent report, the number of persons without access to power in Sub-Saharan Africa grew by 2% in 2020 compared to pre-pandemic levels (Li *et al*., 2021).

1.5. 3. Tanzanian Energy Scenario

1.5. 3. 1. Tanzania in brief

Tanganyika and Zanzibar have been united to become the URT as a single independent entity since April 26th, 1964 (Kalisa and Ndisanga, 2016). Today, the URT contains 30 administrative regions, 25 of which are located on the mainland (also known as Tanganyika) and 5 on the island of Zanzibar. It is the largest of the East African countries, bordered in the south by Zambia, Malawi, and Mozambique, in the north by Kenya and Uganda, in the west by the Democratic Republic of the Congo, Rwanda, and Burundi, and in the east by the Indian Ocean. Tanzania is located between latitude 1° S and 11 45' south of the equator, and longitude 29° 20' E and 40°38' east of Greenwich. The country has a total land area of 947,303km^2. Dar-es-Salaam is a business city while Dodoma is the capital, Swahili and English are the official languages (Swahili being the national language) (Kalisa and Ndisanga, 2016).

Tanzania has low-income East African but with a rapidly expanding population, as evidenced by the increase in population from 51.8 million in year 2016 to 59 million in year 2018 (Tonini *et al.*, 2022). Tanzania ranks in the top ten fastest emergent economies in the world in 2019. The country wants to become a middle-income country by 2025, and to lower the proportion of the people living on less than USA dollars 1.9/ day starting from 48.8 percent in 2015 to a maximum of 4 percent by 2030 (Tonini *et al.*, 2022). This would necessitate pulling about one to three of its population out of poverty in 15 years. Conversely, the country's significant energy poverty will make it difficult to meet these poverty reduction targets (Tonini *et al*. 2022).

The country's economy is greatly centred on agricultural production, 70% of total production is exported, while the same sector creates 75% of total employment. According to the most recent household budget study, 28.2 percent of Tanzanian citizens are still poor (Epaphra and Massawe, 2016). Figure 1.6 indicates the map of Ikukwa ward (Area of study) in Tanzania.

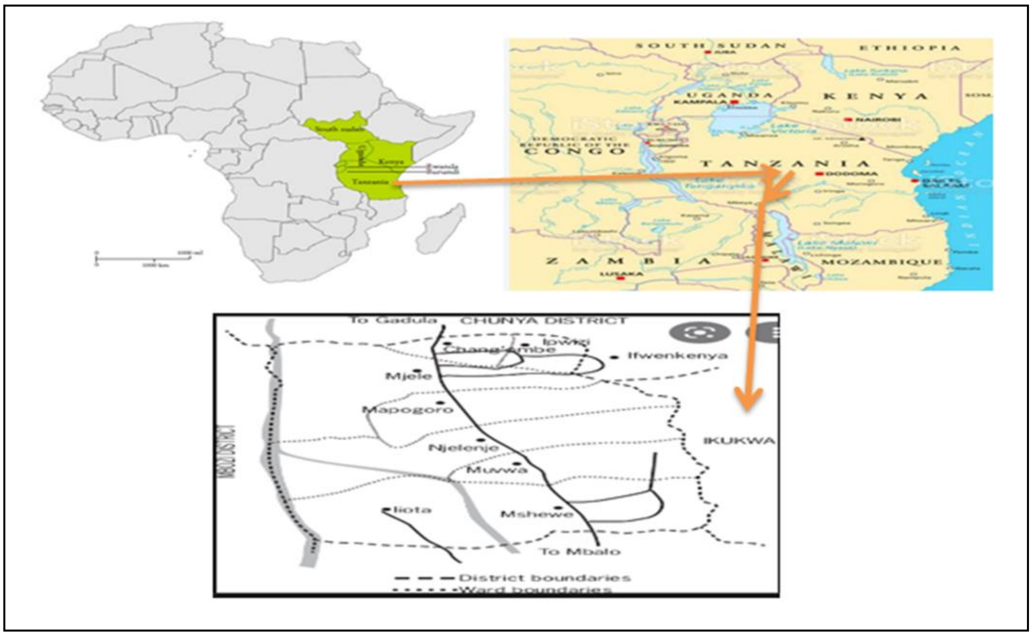


Figure 1.6. Map of Tanzania in east Africa

1.5. 3. 2 Energy Sector in Tanzania

This section provides an overview of the URT's energy sector, discussing the current state of generating electricity, main energy supply, energy usage as well as potential of energy sources.

A. An overview of energy sector in Tanzania

Because of its systemic linkage to other segments of the economy such as, manufacturing, transportation, agro-processing, housing and urbanization, mining, and IT& telecommunication services, Tanzania's energy industry is imperative to the country's economy.

When it comes to power generation, 1717GWh are from the hydro-power, which includes pumped storage facilities, 2566GWh are obtained from gas, 1222GWh are acquired from oil, and 15GWh are from solar photovoltaic use (Kalisa Twizeyimana and Ndisanga 2016). As a result, the total domestic power supply (2013) was 5574GWh for domestic generation plus 59GWh imported from neighboring nations. Electricity losses accounted for 1140 GWh, implying that only 4836GWh of electricity is consumed (Kalisa and Ndisanga, 2016).

Tanzania's energy balance is overtaken by biomass-based fuels, particularly fuel-wood (charcoal and firewood), which accounted for 85 percent of the entire primary energy, 10.7

percent from oil, 3.5 percent from natural gas, 0.6 percent from hydro, and 0.2 percent from coal, though peat and oil shale are aggregated with coal (Kalisa Twizeyimana and Ndisanga 2016. Only electricity generated from non-conventional energy sources and trash energy sources generates 1717GWh, 15GWh from solar PV, and 21GWh from primary solid biofuels (Kalisa and Ndisanga, 2016). Despite Tanzania's average wind speed of 10m/s and other non-conventional energy sources with high potentials such as geothermal, municipal, and industrial wastes, power from those clean energy potentials sources are still underutilized (Kalisa and Ndisanga, 2016). Figure 1.7 depicts share of total primary energy supply.

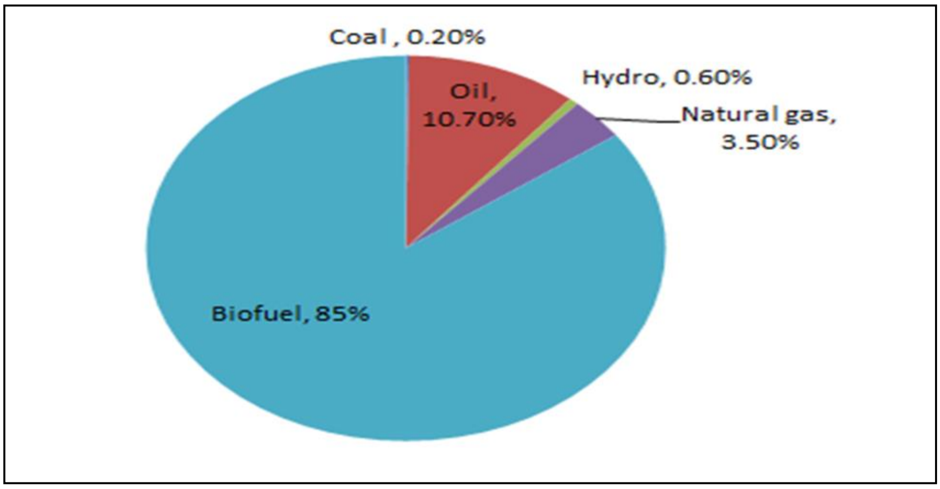


Figure 1.7. Share of total primary energy supply

Tanzania continues to have low electricity consumption rates when compared to other countries. Tanzania's electricity usage per capita in 2013 was 0.09MWh/capita, whilst Kenya and Iceland had 0.17MWh/capita and 54.7MWh/capita, respectively. According to the PSMP (Power System Master Plan) of 2012-2035, Tanzania will achieve an anticipated 75 percent electrification rate for given residences by 2033 (Kalisa and Ndisanga, 2016). Moreover, Expansion Program targeted 500,000 units for the rural residences in Tanzania, including social and civil facilities, providing electrical access to those who would not have had access to power in less than ten years (Tonini *et al.*, 2022). Several non-governmental organizations (NGOs) are active in the country, sparking funding from international aids and lenders due to their long-standing links with domestic agencies and communities.

.Furthermore, Tanzania has found 4.7 GW of hydropower resources; even so, the exploitable hydropower resources are expected to be greater than (Kalisa and Ndisanga, 2016). The entire power generation capacity, as per the government of URT (2020), is 1,565.72MW (573.7MW is derived from hydro energy source), (892.72 MW is derived from natural gas, (88.8 MW is produced from fossil fuels i.e. oil &diesel), and (10.5 MW is generated from biomass) (Kalisa Twizeyimana and Ndisanga 2016). Tanzania has recently begun building of the world's largest hydropower producing plant, JNHPP (Julius Nyerere Hydro Power Project), with a capacity of 2,115MW (Kongela, 2021). Also it is worth mentioning that some advancement has recently been made. The building of JNHPP is planned to increase installed capacity by more than 130 percent, to around 3,700MW. Figure 1.8 indicates share of power installed capacity in Tanzania.

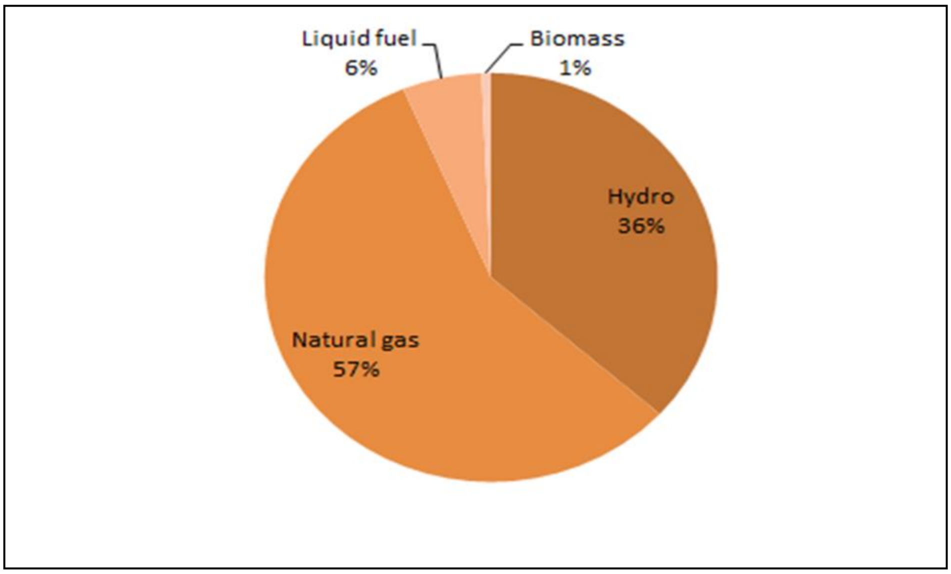


Figure 1.8. Share of power installed in Tanzania

Up to 2014, only roughly 36% of the country's population had access to electricity, with 20% and 16% both urban and rural areas, respectively (Tonini *et al*., 2022). Fuel wood and charcoal are the most commonly used cooking fuels in the country, with a little percentage of paraffin, natural gas, and liquefied petroleum gas (LPG) are largely used in the metropolitan areas/cities (Tonini *et al*., 2022). According to the WB (World Bank), it is only at 38% of the citizens of Tanzania had access to power in 2019 (Tonini *et al.*, 2022). In order to meet the need for electricity, some individuals rely on decentralized systems such as diesel generator, PV (photovoltaic), and various mini-hydro and mini-grid power plants owned by domestic NGOs and faith-based organizations (Kalisa and Ndisanga, 2016). However, the government is also promoting the increased use of natural gas for electricity generation, as well as diversification to other sources like as geothermal, wind, coal, and solar.

B. Administrative organs of energy sector in Tanzania

Tanzania has various institutions in order to undertake various responsibilities and duties for effective and effective management of energy sector. These institutions includes are such as

MOE, TANESCO, EWURA, REA, TGDC, TPDC, ZECO, REF and NEMC. Table 1.1indicates the .institutions of Tanzanian energy sector, establishment with corresponding roles/responsibilities.

Table 1.1: Institutions of Tanzania energy sector, establishment and roles/responsibilities

Institution	Establishment	Roles/Responsibilities
MOE	1964*	Formulation of policies, strategies and Law s (Kassenga, 2008)
TANESCO	1964	(Msyani ,2013)
EWURA	2001	Regulations of electricity, petroleum, NG and water (Ngamlagosi, 2015)
REA	2007	Support for the access to modern energy services (Ahlborg and Hammar, 2011)
TPDC	1969	Exploration and production of oil and gas (Jacob *et al.* ,2016)
ZECO	1964	Distribution of electricity in Zanzibar island (Winther, 2008)
REF	2007	Financing mechanism for rural projects under REA (Kihwele et al.,2012)
NEMC	1983	Enforcement, compliance (Magabe ,2001)
TGDC		Tanzania Geothermal Development Company (Kabaka *et al.*, 2016)

*MOE= Ministry of Energy (Formerly Industries, Mineral Resources and Power), TANESCO = Tanzania Electric Supply Company Ltd, REA= Rural Energy Authority, GER = Geothermal Energy Resource, NG= Natural Gas, EWURA = Energy and Water Utilities Regulatory Authority, TPDC = Tanzania Petroleum Development Corporation, ZECO= Zanzibar Electricity Corporation, formerly State Fuel and Power Corporation, SFPC) REF= Rural Energy Fund, NEMC = National Environmental Management Council, EIA= Environment Impact Assessment , TGDC = Tanzania Geothermal Development Company.

C. Potential, use and planning of energy resources in Tanzania

(a) **Biomass energy resource**

In Tanzania, biomass accounts for the lion's share of primary energy use. Biomass energy is employed in a variety of forms, which can be divided into two types: woody feedstock and agro-forestry wastes (animal manure, wastes derived from the crops plus wastes from forests). These fuel commodities can be combusted or transformed into solidified type (e.g. charcoal), liquid type (e.g. ethanol), and gaseous fuels before being burned (e.g. biogas from anaerobic process), (Aslam et al., 2021). Almost 80 % of citizens of Tanzania use biomass (firewood/charcoal) mainly for food preparation and heating purposes (Aslam *et al.*, 2021. In Tanzania, however, the biomass is harnessed in classical and un-sustainable methods. A million people are employed in the preparation and supply of charcoal. Deforestation is a major source of biomass energy resources due to a lack of laws and coordination (Aslam et al., 2021. Unsustainable charcoal manufacturing causes 100,000 to 125,000 hectares of annual forest degradation, and the Tanzanian government loses approximately US $ 100 million in revenue each year (Aslam *et al.,* 2021). Currently, biomass is used to generate power, with the first 18 MW going to the grid and the remaining 58 MW coming from agro-industry generating. The potential for modern biomass use is immense, with 1.5 million tonnes of sugarcane bagasse harnessed per year (Mil. tonnes per annum), coffee husk (0.1 Mil. tonnes per annum), sisal (0.2 Mil. tonnes per annum), rice husk (0.2 Mil. tonnes), forest residue (1.1 Mil. tonnes per annum), and municipal solid waste (4.7 Mil. tonnes per annum), as well as fuel wood from fast-growing tree plantations (Kalisa and Ndisanga, 2016).

(b) Coal energy resource

According to the Tanzania energy sector's pre-assessment report prepared in accordance with the principles of the IEC (international energy charter) and the ECT (energy charter treaty) of 2015, the probable capacity of coal is approximately 1.2 billion tonnes, with only 30% of reserves proven, which is equivalent to 304 million tonnes (Kalisa and Ndisanga, 2016). According to the power Africa's 2014 annual report, proven reserves are totalized up to 1.9 billion tonnes. Kiwira, Rukwa, Mchuchuma (Katewaka), and Ngaka are among of the locations with coal reserves. In addition, there are exploitable 220 mil. tonnes of the same reserve around the Lake Victoria (Kalisa and Ndisanga, 2016). Currently, no power is created from coal, although the government intends to utilize these resources for electricity production (Kalisa and Ndisanga, 2016).

(c) Natural gas energy resource

The URT has been exploring for oil and gas since 1974 on Songo- Songo Island. The field wasn't even explored at the time due to funding constraints. After barely six years, TPDC found oil natural gas and oil in Mnazi Bay, Tanzania's southernmost region. In 2010, finds were made in the Mtwara district of Tanzania's southern-most region. The total amount of proved natural gas in the country is expected to be 46.5 trillion cubic feet (TCF) (December, 2013), which is comparable to more over nine billion barrels of oil (Kalisa and Ndisanga ,2016). Tanzania, on the other hand, is still reliant on imported petroleum because the oil has yet to be discovered (Kalisa and Ndisanga 2016). In Mnazi Bay and Songo-Songo, just four TCF have been explored. The latter is used to feed gas to various gas-fired power plants, including Kinyerezi Phase ONE, Phase TWO, Phase THREE, and Phase FOUR, which have capacities of 150MW, 240MW, 600MW, and 500MW, respectively, and Kilwa Energy, which has a capacity of 210MW(Kalisa Twizeyimana and Ndisanga 2016). Furthermore, Tanzania is currently planning to construct a new facility on the outskirts of Dar es Salaam near Mkuranga (Kalisa and Ndisanga, 2016).

(d) Petroleum energy resource

Tanzania's petroleum resources are not yet fully proven and developed. As a result, the entire country is dependent on imported gasoline products, both refined and crude. Total imported oil products account for 30% of total imports. Only 40% is utilised locally, while 60% is transferred to neighbouring countries such as Burundi, the Democratic Republic of the Congo (DRC), Malawi, and Rwanda while the nation of Zambia receives crude oil through the pipeline from Dar-es-Salam port to Ndola (Kalisa and Ndisanga 2016).

(e) Uranium energy resource

Tanzania's uranium potential was discovered in the 1970s, and investigation ended in the year 2005, revealing exploitation reserves in the area of Namtumbo, Ruhuhu close to the Lake Nyasa (Ruvuma), Manyoni (Singida), and Bahi & Handa (Dodoma) (Kalisa and Ndisanga ,2016). Tanzania does not yet have nuclear power, despite its uranium energy potential, but it has organized a task group (level) in charge of developing nuclear technology to increase electricity capacity ((Kalisa and Ndisanga, 2016).

(f) Hydro energy resource

According to studies, Tanzania's topography is the most suited for medium to high head micro and pico hydro power the run-of- river facilities. Tanzania's total technical hydropower capacity has been approximated at 4.7 GW, with just 12% currently being utilized [(Kalisa and Ndisanga, 2016). Although this changes depending on the region, the Tanzanian nation is located in the Great Lakes region, specifically Lakes Tanganyika, Nyasa, Rukwa, Rukwa, Eyasi, Natroni, and Manyara. Tanzania also features rivers such as the Rufiji (Rufiji basin), Kagera (Lake Victoria basin), Malagarasi (Lake Tanganyika basin), Ruvuma (Ruvuma and Southern Coast basin), Mara (Lake Victoria basin), Pangani (Pangani basin), Ruaha (Rufiji basin), and Wami (Wami Ruvu basin) (Kalisa and Ndisanga, 2016).

(g) Geothermal energy resource

Geological, geochemical, and geophysical studies indicate that Tanzania has potential of geothermal energy in the majority of the Eastern Rift Valley routes (Kalisa Twizeyimana and Ndisanga 2016). Manyara, Songwe (Mbeya), Luhoi (Rufiji), Lake Natroni, and Kisaki are among them (Morogoro). Geothermal potential is predicted to create roughly 650MW of power, although only 140 to 380MW have already been tapped to date (Kalisa and Ndisanga ,2016)

(h) Wind energy resource

The electric wind potentials of Tanzania's highland plateau and locations traversed mostly by rift valley have been assessed. At 30 m, Makambako (Njombe) and Kititimo (Singida) have promising wind speeds of 8.9 m/s and 9.9 m/s, respectively (Kalisa and Ndisanga, 2016). Further assessments are being carried out by the responsible energy authorities (MEM, TANESCO, and REA) in the areas of Makambako (Njombe), Mkumbara (Tanga), Gomvu area (Dar-es-salaam), Litembe (Mtwara), Kititimo (Singida), Mgagao (Kilimanjalo), Usevya (Mpanda) , and Mafia Island (coastal region), until 2015, firms have shown an interest in generating wind energy including Geo-Wind Tanzania Ltd, Tan Renewable Energy Limited in the Makambako, Wind East Africa in Singida and in Sino, Njombe region, and Wind Energy Tanzania Ltd (Kalisa and Ndisanga, 2016). However, Power Pool Africa was one step ahead of the competition, obtaining a power purchase agreement for providing 100MW of electricity from a wind farm at Kititmo area (Singida region) (Kalisa and Ndisanga, 2016)

(i) Solar energy resource

Tanzania has a good sun irradiation ranging from 4 to 7 kWh / square metre per day (4 - 7kWh/m^2/day) based on its geographical location, according to a solar radiation map. The energy potential ranges from 2,800 to 3,500 hours of sunshine per year, and solar energy is particularly abundant in the country's core regions, making it a good and dependable answer to electricity needs for both on-grid and off-grid connections (Kalisa and Ndisanga ,2016) . According to the researcher's experience, the use of solar power in the country is highly beneficial and installations of solar power systems have appreciably taken off and more same systems of different capacities are in in the implementation and planning stages so as to reduce the energy shortage in the country. The utilization of solar energy in the country is in parallel with the global growth of solar energy applications. Therefore, following is the presentation and brief discussion about the utilization of solar energy in Tanzanian environment:

(j) Decentralized solar photovoltaic (SPV) off-grid systems

Currently, electricity generated is used in a variety of purposes, including schools, health centres, hospitals, public offices, public road lighting, commercial buildings, private firms, as well as and domestic residences . Aside from that, there are mechanisms in place to spread and strengthen the sustainability of solar technologies, particularly in off-grid areas, such as the SSMP (Sustainable Solar Market Package) and lighting (Kalisa and Ndisanga, 2016). Both solar PV schemes in rural Tanzania are sponsored by the government of URT through REA and various donors (Kalisa and Ndisanga, 2016).

(k) Grid connected solar PV power system

Tanzania has recently reconstructed a single solar PV power station in the central region, which generates approximately 1,800 MWh per year and it occupies a single hectare of land (Kalisa and Ndisanga 2016, Mnzava, et al. 2022). Based on the PSMP (Power System Master Plan), solar energy will account for 20% of total generated capacity (800 MW out of 4,700 MW highest demand) by the year 2025 (800 MW of the total 4,700 MW peak demand). Tanzanian government was targeting to generate the power capacity of 120 MW of solar power by 2018 (Kalisa and Ndisanga, 2016). The market is great for investments capacities ranging from 50 MW to 100 MW of solar PV powered system, but only NextGen is eligible. An agreement between Solawazi and the government of URT has been signed for the delivery of 2 MW derived from solar electricity to an autonomous grid system; while TANESCO anticipates to construct the capacity of 1 MW solar PV grid connected PV plant (Kalisa and Ndisanga 2016, Mnzava *et al.*, 2022).

(l)Thermal systems derived from solar energy

Tanzania has undeniably high solar thermal energy potential, which is commonly employed to support agriculture for directly drying wood and crops such as coffee, cereals, pyrethrum, etc. Limited thermal systems of solar energy has also been constructed to heat water particularly in some families and institutions such as hospitals, hotels, dispensaries, and health centres through the use of solar water heaters. Still, due to constraints such as lack of awareness, funding issues, and mentality (poor priority given to investment), the use of solar thermal and warm water heated by solar is at a low level (Kalisa and Ndisanga, 2016).

These renewable energy sources may have made a significant contribution to addressing the nation's power crisis, particularly in transportation, tourism, telecommunications, mining, industries, and agriculture. However, the development of these non-conventional energy resources in Tanzania is hampered by a number of obstacles, including a lack of human capital and training, high investment costs, limited awareness, minimal and limited research and development, a centralized approach (monopolized) regarding the institutional framework, and a preference for centralized electricity from the national grid (TANESCO), which leads to a low adoption of decentralized power schemes.

1.5. 3. 3 Energy scenario at designated place of study in Tanzania

Ikukwa Ward (formerly was known as Ikukwa village) is located in Mbeya rural district, Mbeya region, Tanzania, East Africa. It was established in 1972 under "*Vijiji vya Ujamaa*" programme in the post-independence period under the first president of the Tanzania the late Julius Kambarage Nyerere. The main target of the programme was to re-allocate the scattered rural residences into pre-determined place so as to acquire suitable social pattern of dwellings for simplicity and easiness of effectively providing necessary services like education, water supply, electricity supply, and so on. In 1998, the former Ikukwa was divided into two villages and therefore creating Ikukwa and Simboya villages. Ikukwa village comprises of fourteen sub villages and Simboya village has nine sub villages. Therefore whole ward has two villages with a sum of 23 sub villages (*vitongoji*). Main economic activities for Ikukwa ward are agriculture and livestock keeping.

Generally, this location a limited access to modern energy services including electricity. According to the survey, Ikukwa village has limited access to grid connectivity almost being negligible (before 31, August, 2018). Simboya village has no access to the national grid (TANESCO), based on the researcher's survey before 31, August, 2018. The residents at this particular area of study use conventional energy sources like kerosene, candles, small-sized diesel generators, and biomass (firewood and charcoal for meal preparations and heating applications). These traditional energy sources are not cost-effective; provides energy insecurity, for instance, during the political instability in oil producing countries, finiteness (depletion), and are ecologically friendly. The excessive traditional utilization of biomass can lead to unsustainable deforestation and health problems users due to pollution from harmful gases and global warming effects. Figure 1.9 indicates the maize flour/huller milling machine driven by diesel (Left side) and local fabricated diesel power plant for welding activities, lighting, and charging mobile phones (Right side) by Ikukwa residents.

Figure 1.9. Maize flour/huller milling machine driven by diesel (Left side) and local fabricated diesel power plant for welding activities, lighting, and charging mobile phones (Right side) at Ikukwa residents (Source: By author)

Selected area of research is blessed with renewable energy sources such as biomass derived from animal wastes, solar, hydro source and wind. In this particular area solar products and few solar house systems have been implemented. Hydro power source (from River Shongo) is mainly used for drinking, irrigated farming and livestock. Currently, animal waste (manure) is used for fertilizers, not appropriately disposed and thus is wasted. The use of this availability of renewable energy sources for delivering electricity supply to the area of study is necessary for increasing access to sustainable, reliable and affordable electricity. In addition and also in particular, the use of animal wastes for energy production is important as it assures local energy independence; minimize energy cost and disposal management costs. Utilization of animal wastes for energy production is important as it ensures local energy independence; minimize energy cost and disposal management costs. Currently, animal waste (manure) is used for fertilizers, not appropriately disposed and thus is wasted. Therefore, decentralized renewable energy-based systems, either of a single source or hybridized, can be used to produce electricity close to the utilization point at minimum cost with high efficiency and reduced time of implementation in comparison with grid system. Technicality (technology) and cost are important parameters requiring systematic and comprehensive techno-economic analysis of renewable energy based systems.

1.5. 4 Conclusion and Adoption of Renewable Energy Resources at the Area of Study

In today's society, energy is an essential aspect of our daily lives. Economic progress of a particular country is associated with rate of energy consumption. Energy, for instance, is required for cooking, cooling, transportation, and water pumping, among other energy social services. For a long period of time, fossil fuels have been used for meeting energy requirement worldwide. However, these conventional fuels are scarce, depletive, insecure, and expensive and are also pollutants. In addition, extending grid to these off-grid locations of developing countries is expensive, extended time of implementation as normally are huge projects and limited budgets and capacity of expertise. Moreover, in some areas power grid is unreliable (e.g. frequent power cuts and shedding) and inefficient due to long distances and outdated grid infrastructures.

Renewable energy can eliminate or reduce the need for electricity in rural areas as it can be cost effective and eliminate pollution for the health of consumers and sustainable development. Renewable have been appreciably adopted globally, regionally and nationally including Tanzania. Therefore, in this direction the energy available in a particular area can be used so that low-cost electricity can be obtained without polluting the environment. By applying the same logic/sense the renewable energy available in Ikukwa ward in its two villages can use renewable energy to eliminate the problem of cheap electricity without environmental pollution for good living, comfort and health of users. Therefore, consideration of energy generation through renewable energy sources is important to address the problem of energy shortage in rural areas of developing countries including Tanzania and to collaboratively mitigate the harmful emissions. For instance, solar PV technology and small hydro power technology are widely used methods for generating electricity in Tanzania.

Fortunately, there is an opportunity of high potential of local renewable energy resources of the selected location of study (Ikukwa ward) can be fully tapped to meet energy demand. Renewable energy based micro grid reduces the dependence on main grid power supply, improves power quality and minimizes the cost of energy storage system. From above discussion it may be narrated that renewable energy such as solar and wind energies have intermittency nature needing the hybridization of complementary power sources or storage energy systems for acquiring reliability and maintaining power stability. Due to the variance of renewable energy sources hybrid of multiple energy sources are integrated into the hybrid micro grid system. These hybrid systems are promising choice for meeting energy requirements in educational institutions, hospitals, industries, telecommunication towers and remote rural communities. However, designing process for cost-effectiveness and reliability of hybrid renewable energy systems for different applications is difficult as it involves different energy sources with different characteristics. Furthermore, the specific information of renewable energy based system for a particular application of a given place is actually not known. Design of any hybrid renewable based system should sound both technically and economically. In other words, technicality (technology) and cost are critical parameters that necessitate a thorough techno-economic performance analysis of any renewable energy-based systems for particular off-grid applications.

2.4. 5 Why Solar Energy-Based Systems in This Study?

The utilization of solar energy is classified into the two types of main technologies: photovoltaic (PV) catchers and other solar thermal collectors such as water heater catchers, air heater collectors, and concentrating solar collectors (Mohammadi *et al*., 2020). In this study, all proposed configurations for various applications are solar PV energy based systems (single or multiple renewable energy sources). Why solar PV energy- based systems? These are reasons of proposing solar PV energy based systems: Sunlight can be used as a primary source of energy or in conjunction with other non-conventional or conventional power sources (fossil fuels) to power single and multigenerational systems. Sunlight multi -generation systems are intriguing due to the widespread availability of solar radiation in most regions of the world, as well as the availability of a wide range of technologies which can be used. Solar-powered multi-generation systems provide numerous advantages, including the ability to generate numerous useful materials in an environmental benefits and sustainable manner, enhancing overall thermodynamic (for thermal systems) efficiency, lowering capital investment and item costs by sharing components and lowering greenhouse gas emissions. Solar collectors are used to capture available solar energy (Mohammadi et al., 2020).

2.5. 6 Main Goal and Specific Objectives

Therefore, the aim of the proposed research work is to perform techno-economic analysis of renewable energy based micro grid systems for various rural applications. Specific objectives for this study are presented as follows:

(i) To perform feasibility analysis for design and development of micro for a given area.

(ii) To perform integration of RES to micro grid system for providing power to rural areas.

(iii) To develop and implement intelligent techniques for modelling and sizing of renewable energy- based micro grid system.

(iv) To perform optimization of energy storage systems of renewable energy based micro grid.

1.4. 7 Research Approach and Contributions

The limited accessibility to energy in rural areas of developing countries including Tanzania can be addressed using local renewable energy resources. Also, decentralized renewable energy-based systems can solve the problem of unreliable power grids accompanied by frequent outages and power shedding in both rural and urban locations of developing countries. The local renewable energy resources are useful for global collaborative combat against the environmental concerns caused by fossil fuelled systems. As far as the design of these systems is concerned, information on technical and financial parameters is important prior to implementation of any system for a particular application.

This research work involves the heterogeneity (assortment) approach of analysis consisting of a variety of techno-economic analyses of the decentralized renewable energy based systems (dissimilar configurations) for the various applications at the proposed rural area of study. This study mainly examines hybrid decentralized systems for the selected area of study. SPV and Hydro power systems are mature technology in the country. This study involves the hybrid biogas energy based systems which are currently being researched in the country and the use of abandoned potential of non-perennial tributary located in high land zones. The study evaluates single sources systems of solar photovoltaic with batteries for rural residence applications and small wind system for power and small irrigated farming for a rural residence located at the area of study. These different renewable energy-based systems of dissimilar optimal configurations are envisioned to supply electricity to Ikukwa ward specifically at Ikukwa village, Simboya village, rural house with irrigated small scale farm, and typical rural residence. Both typical rural residence and peasant’s rural house with irrigated small scale farm are located at Simboya village. Figure 1.10 provides an overall research approach.

1.6 RESEARCH APPROACH

(i) HOMER pro software has been used to obtain optimal configuration of individual of renewable energy-based system at the least value of NPC and its corresponding LCOE.

(ii) Artificial intelligent techniques (Nature inspired methods) such as PSO, GWO and their hybrid techniques (GWO-PSO) to optimize the renewable energy based systems.

(iii) Mathematical modelling of the proposed systems for different applications have been carried out

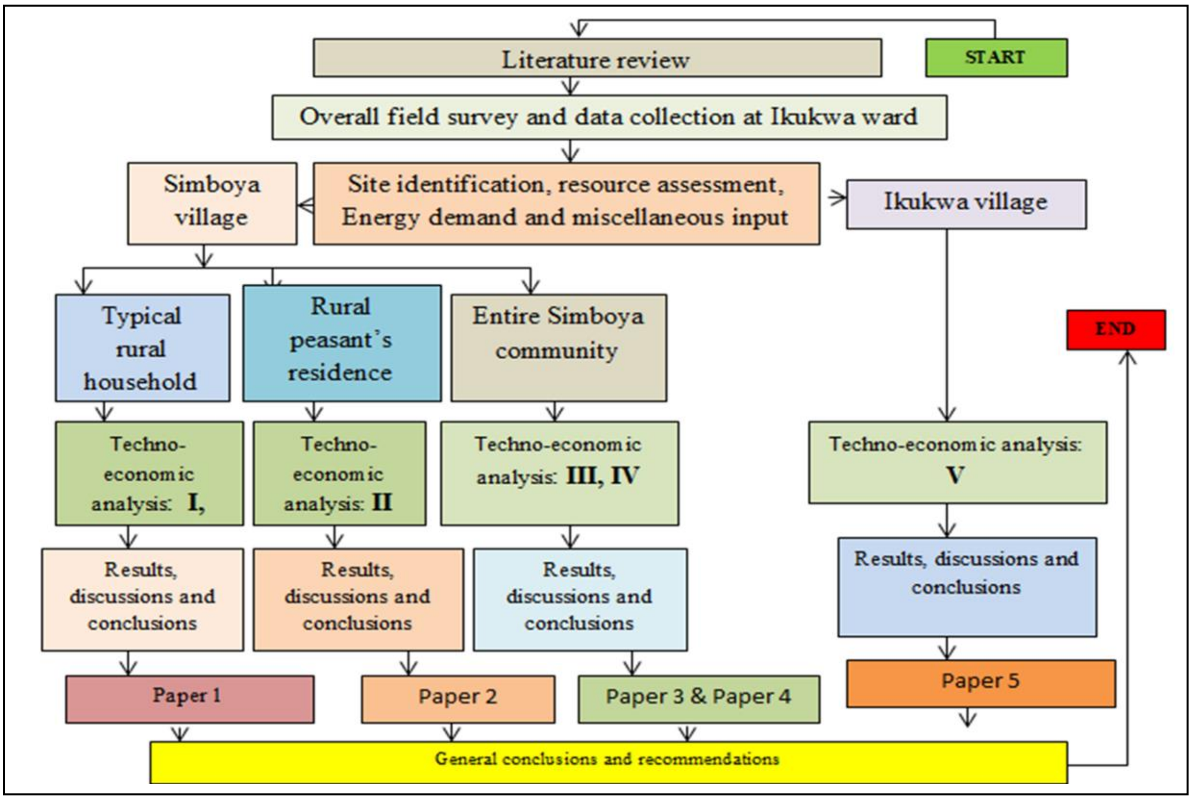


Figure 1.10. Overall research approach

LEGEND*:* ***I***. *It represents the techno-economic analysis of standalone SPV integrated with battery energy storage system anticipated to provide power supply to typical rural home located at Simboya village using HOMER platform*. ***II.*** *It embodies the techno-economic analysis of SWTES for electric power and water supply for peasant's residence located at Simboya village using HOMER platform.* ***III.*** *It expresses the techno-economic analysis of the configuration of hybrid SPV/ hydro /Battery system using HOMER pro and GWO algorithm.* ***IV.*** *It articulates the techno-economic analysis of the configuration of SPV-Hydro-Biogas -Battery bank system, expected to supply electricity Simboya village.* ***V.*** *It represents the techno-economic analysis of the configuration of PV/Small hydro /Battery energy system expected to supply electricity to Ikukwa village using HOMER pro software and GWO - PSO hybrid platforms.*

Contribution of the research articles of this thesis are presented in the alignment of research problem, main goal and specific objectives, and are systematically presented in the light of the configurations **I, II, III, IV, and V** as explained above. The publications of papers with their statuses in brackets are briefly described as follows:

- Paper 1 (Published) is related to the techno-economic analysis of standalone SPV integrated with battery energy storage system, Configuration **I** in Chapter 3. The research article has been analyzed using HOMER and PSO technique platforms.
- Paper 2 (Published) is related to the techno-economic analysis of SWTES for electric power and water supply for peasant's residence, Configuration **II** in Chapter 4. The paper has been modeled and optimized using HOMER platform.
- Paper 3 (Under review) is related to the techno-economic analysis of hybrid SPV/ hydro /Battery system, Configuration **III** in Chapter 5. The research article has been carried out using HOMER and GWO platforms.
- Paper 4 (Submitted) is related to the techno-economic analysis of hybrid SPV-Hydro-Biogas -Battery bank system, Configuration **IV** in Chapter 6. The paper has been modeled and optimized using HOMER platform.
- Paper 5 (Published) is related to the techno-economic analysis of SPV/Small hydro /Battery energy system, Configuration **V** in Chapter 7. The research article has been carried out using HOMER and hybrid GWO - PSO technique platforms.

All research objectives are accomplished. Here, objective (i) is covered in all configurations depending on the rural applications; objective (Chapters 3-7) (ii) has been covered by Standalone SPV system and all hybrid configurations (Chapters 5, 6, and 7), objective (iii) is accomplished in **I**, **III** and **V** (Chapters 3, 5**,** and 7), and objective (iv) is accomplished in, **III** and **V** (Chapters 5 and 7). Details on publications are provided at the end of the thesis report.

1.8 CONCLUSIONS

High demand of energy, environmental concerns and the challenges from the poor grids in most of the developing countries can be addressed via local SRES's. The intermittency of renewable energy sources can be addressed through the deployment of ESS and by the combination (hybridization) of appropriate complementary sources of energy. The task of integrating energy sources to form any hybrid renewable energy micro-grid system is complex requiring detailed analysis. In the analysis technological and economic aspects are important metrics to be exhaustively investigated.

1.9 THESIS OUTLINE

The presented research work is mainly focused on the hybrid renewable energy based micro-grid systems for different applications intended to electrify rural and remote areas located at Ikukwa ward in Mbeya rural district, Tanzania. Thesis consists of in eight chapters and is outlined as follows:

Chapter- 1 Provides the introduction of energy, importance of renewable to acquire energy security, solve shortage of energy and mitigate harmful emissions, global and local energy scenario (country wise and selected area), and design proposed different types of renewable energy systems (mainly the hybrid energy systems) for miscellaneous applications.

Chapter- 2 Presents the review of relevant research literature. The presentation starts with the description of preliminary themes for an intention of highlighting important many aspects of designing decentralized renewable energy based systems for rural electrification. Second part, presents the state of the art, problem statements and research gaps.

Chapter- 3 Presents the techno-economic feasibility analysis of solar PV (SPV) with battery energy storage system for supplying electricity to a typical rural residence in Tanzanian environment. It presents the mathematical modeling and optimization analysis of proposed system using HOMER and PSO technique platforms. Also, this chapter also presents the comparative analysis between the SPV system and its equivalent DG at same load demand.

Chapter- 4 Presents the techno-economic feasibility analysis of small wind turbine electric system (SWTES) for both applications of both small irrigated farming and power supply to domestic rural house located in the area of study. Optimization analysis of proposed system has been implemented in HOMER pro software.

Chapter- 5 Presents the techno-economic feasibility analysis of proposed hybrid solar photovoltaic (PV)/biogas/battery bank anticipated to supply power to Simboya village, Mbeya rural district, Tanzania, East Africa. . It presents the mathematical modeling and optimization analysis of proposed HRESS using HOMER pro software and GWO method. The economic performance of the proposed off-grid system is compared with other configurations in terms of types of technologies used and economic distance limit (breakeven) of grid extension. Finally, both sensitivity and environmental analyses are also presented.

Chapter- 6 Provides the techno-economic analysis of SPV-Hydr*o*-Biogas-Battery bank system, expected to supply electricity to Simboya village located at Simboya village in Mbeya rural district, Tanzania. HOMER platform was used for modelling and optimization of the system of the off-grid HRESS.

Chapter- 7 Describes the techno-economic analysis of the configuration of SPV/Small hydro /Battery energy system expected to supply electricity to Ikukwa village using HOMER pro software and GWO - PSO hybrid platforms.

Chapter- 8 Summarizes the conclusions, recommendations, contribution of the research work and description of the future research works.

CHAPTER 2

LITERATURE REVIEW

2.0 GENERAL

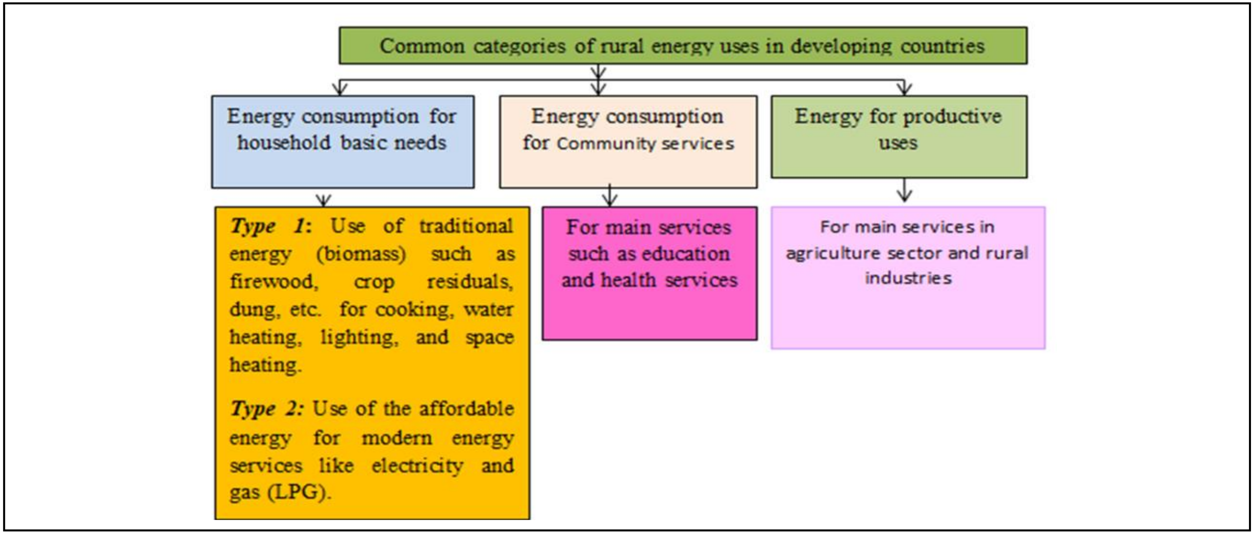
First part of literature review starts by shedding light on important relevant various theories to understand in-depth knowledge related to rural power generation using renewable energy, especially in reducing the high energy demand in developing countries including Tanzania. This is to say that the aim is to build a foundation before going through the different aspects, research and case studies and how have been carried out in various parts of the world to generate electricity for rural areas. Therefore, the first part of the literature review consists of preliminary topics which are supplemented by the examination of different case studies with their corresponding methods which have been already carried out previously. This extremely helps to identify and explain research gaps (loopholes) to be examined within this current research.

2.1 PRELIMINARY RELATED MISCELLANEOUS THEORIES

This part of this chapter presents the preliminary miscellaneous related theories for in-depth understanding of rural electrification in developing countries, renewable energy technologies, hybrid electric micro –grid systems, power management of micro grid system, optimization techniques, energy storage systems etc.

2. 1.1 Concepts of Rural Electrification and Energy Uses

The meaning of rural area can differ from one place to another of from a nation to another. Therefore there is no agreed or universal definition of the term "*Rural Area*". However, the rural area is characterised as follows: their typical features are quite clear. Rural areas are often sparsely populated, geographically remote, and difficult to access in basic developing countries (Mainali and Silveira, 2013, Mandelli, et al., 2016). Pastoralism, cattle-raising, agriculture, fishing, tourism, and forestry are the main sources of income for rural households (Lahimer *et al.*, 2013). Due to poor road conditions and great distances from metropolitan areas, service providers are unable to guarantee regular visits, hindering local communities from engaging in national or regional marketplaces. High-educated people (teachers, doctors, technicians, and so on) are especially despondent to live in such locations (Schäfer *et al.*, 2011). Rural areas are also affected by high illiteracy rates, gender inequality, a lack of access to health care, infrastructure (roads, markets, information), and clean water (Lahimer *et al.,* 2013). Due to the mentioned reasons, residents of rural areas have limited access to modern energy services including electricity and therefore population of rural areas particularly in developing countries are absolutely not privileged. The provision of electricity to these rural areas is termed as "*Rural electrification*". In the author's view, the term *rural electrification* may be defined as a process of increasing sustainably, equitably and universally energy access to the rural populace. However, the number of towns and villages connected to the national centralised grid is often limited to those along important roadways and nearby locations. When it is available, only the wealthiest households, businesses, and community organisations can afford to connect (Murphy,2001; Lahimer et al.,2013; Karekezi and Kithyoma 2002, Bhattacharyya 2006), as energy can cost up to ten times more than in metropolitan areas (Kaygusuz, 2011). When there is no centralized grid connection, electrification takes place in places where local fuel supplies are available, and it is based on off-grid small-scale power generation such as MCG's & MNG's . As in most cases in rural areas of underdeveloped countries access to electricity by grid extension is limited, decentralized energy system such as conventional (Diesel generators) and renewable energy based system (Single or hybridized power sources) are deployed (Zebra, et al., 2021). Rural electrification offers energy services to rural dwellers in residential, communities and for the productive purposes (Mandelli et al., 2016). Figure 2.1 shows categories of energy consumption in developing countries. The electrification to these rustic and isolated areas can be implemented via distributed generation and national central grid power networks.



2.1. Categories of energy consumption in rural areas in developing countries (Source: Author).

Generally, rural electrification in developing countries is imperative for social, economic and sustainable development.

2. 1. 2 Introduction to Rural Electrification

In the up-to-date world, energy is strongly related with the economic and social progress of any nation. According to the information realized from the international energy agency (IEA), it is not less than 1.2 billion out of the total population worldwide have access to the modern energy services. It is about 95% of the population without access to reliable energy resides in African and Asian regions, out of which 80% of the population live in the rural areas (Nugroho *et al.*, 2022). Therefore, rural electrification for the improvement of standards of life in the rural and isolated regions is unavoidable. In developing countries, rural electrification is implemented mainly by the fossilized sources of particularly diesel generators and/or grid extension (Sandwell *et al.,* 2022). Yet, power supplied to the rural areas has poor quality and is unstable. Conventional power generation methods are not cost-effective and sustainable (Nishanthy *et al.*, 2022). Luckily, nowadays there are substantial technological advancements (enhanced efficiency), maturity and trend of the decline in costs of renewable energy power sources and therefore deployment of decentralized renewable energy systems are imperative for rural electrification implementation in developing countries (Harish *et al.*, 2022). The function of distributed generation in national rural electrification planning is directly relevant to the quest for universal energy access. Access to electrical energy is a key factor in GDP growth and development and thus an investigation of the distribution generation systems for rural electrification is paramount of importance particularly in the poor remote areas of SSA region (Bilgili *et al.*, 2022) (Mungai *et al.,* 2022). In the future, distributed power generation (DPGE) will become increasingly significant. The transition from traditional fossil fuel generation to green off-grid and mini-grid (MNG) energy is speeding up. Although grid extension is still the most common method of rural electrification, only half of new electricity connections will be generated by conventional means by 2030, with the balance supplied by mini grids (MNG's) and micro-grids (MCG's) (Juanpera *et al*., 2022). Grid extension is already helping densely populated parts of SSA, such as cities and towns, achieve universal electricity (Juanpera, *et al.* 2022). Though disruptions may contribute to a huge market for back-up solutions in these nations, dispersed electricity production will likely play a limited part in household electrification. The fundamental constraint of (DPGE) is the small size of the generators.

2. 1. 3 Rural Electrification in Developing Countries

Small-scale generation technologies are becoming increasingly important in the planning of both developed and developing countries' electric utilities. Nevertheless this is not a new approach (Mandelli *et al.,* 2016). In fact, at the dawn of the electrical era, systems were centralized, and tiny power units, along with batteries, supplied electricity via dc grids only to areas of intensive load (Delboni *et al*., 2019; Korkovelos *et al.* 2020).The first period of small-scale generation was ushered in by the development of ac grids and technological breakthroughs in generation plants, which led to the creation of major transmission grids and power plants (Dunn and Peterson, 2000). The ensuing organization of the electrical sector was a state-owned vertically integrated regulated monopoly, which can be thought of as the basic paradigm of centralized electricity. While wealthier countries were able to enlarge the coverage area of the electric grid, developing countries were unable to do so. Developing countries are still facing considerable difficulties in increasing power production and electrification rates (Paiho *et al*., 2021). Rural areas are the most afflicted by this situation since governments paid more attention to urban areas where economic activities are relevant. Rural electricity supply generally results to be expensive within the centralized approach, and hence the utilities have always been reluctant to extend the service to rural areas (Bhattacharyya and Palit, 2021). Typical actions taken up by developing countries governments to address this issue were the establishment of separate organizations the rural electrification authorities which were made responsible for rural electrification programs (Zebra *et al.,* 2021).The primacy of the centralized approach gradually decreases .In developed countries, in ‘80s, due to an introduction of competition implemented electric industry reforms. Also, developing countries pursued reforms trying to attract foreign private capitals in order to make more effective and efficient the existing power system and to increase the efficiency in the electrification process (Twesigye, 2022). It is in the new post-reform frame that a second era of small-scale generation systems, mainly based on renewable sources, seems to arise. Besides the introduction of competition, other factors contributed to renew the interest towards a strategy based on small scale generation systems. Revising the literature, were cognized and propose to group these factors according to five dimensions: environmental, economic, technical, political and social. Most of the listed factors are driving forces that support small-scale generation in developed countries as well as in developing countries Nevertheless, further reasons can be associated specifically to developing countries and rural areas: Small-scale generation, based primarily on renewable sources, is recommended for remote regions where costs make the extension of the main grid impracticable (For enhanced accessibility and affordability), remote locations, particularly those that are not electrified, have relatively low demand and low load factors, making small-scale generation systems suitable (Mandelli *et al.*, 2016). The shift by international institutions after 1995 towards poverty-based strategies, with initiatives such as the Millennium Development Goal (MDG) and the International Year of sustainable energy for All, focused attention on the links between modern energy and poverty (i.e. the importance of energy services to improve livelihood conditions by meeting basic needs) (Mkhize, 2021). This has led to the inclusion of electricity as a key component in rural development programmes, with small-scale generation as the preferable option for rural electrification, and despite the fact that critics have advanced, the premise that developed countries can circumvent some of the processes originally followed in developing ones by embracing the most modern technologies is remains appealing (Mkhize, 2021). Small-scale generation, mostly PV for rural regions, has been highlighted as an instance of leapfrogging *(Neupane et al.*,2022). Off – grid systems are better solution to developing countries (Decentralized/Distributed power generation systems) are better solutions for expanding access to electricity in developing countries (Gill-Wiehl *et al.*, 2022). It is noteworthy to give a short description of off –grid systems as follows:

(a) *Decentralized networks* (systems) are made up of autonomous components that do not interact with each other during conversion and distribution. Locally focused and need-oriented, such systems are frequently adapted to specific localized energy needs and rely solely on indigenous energy sources (non-conventional energy sources). Furthermore, this idea encompasses systems that provide power to a single or multiple consumers in a neighbouring area (Clapes , 2021). This helps to differentiate between stand-alone and micro-grid systems by using the client number category. The first refers to systems that supply electricity to a single, proximate consumer (e.g., a residence, a kiosk, a countryside industry, an education institution, etc.), while the latter refers to systems that give power to a group of consumers (e.g., a village of dwellings, a market area of kiosks). The latter refers to power distribution systems that supply power to multiple, similar or different consumers (for example, a gathering of dwellings in a community, a number of shops in a commercial area, a cluster of farmer houses with mills and pumping stations, a village with residences, school, health centre, and rural industries) (Mandelli *et al.,* 2016). Furthermore, taking into account the rural energy uses categories; can be distinguished as home-based systems, community-based systems, and productive-based systems within stand-alone systems. Systems in the latter group may require a localized distribution system at times (Mandelli *et al*., 2016).

(b) *Distributed networks* are made up of multiple decentralized conversion units that are linked and interact via a distribution grid. As a result, a virtual power plant with various generation locations and a master brain for centralized control is created, which receives data about the system's operational status and decides how to manage it. These systems are referred to as hybrid micro-grids. Hybrid micro-grids are made up of various conversion units that can use a variety of energy sources and supply power to one or more consumers, the latter of which can be of various energy consumer types (Saponara *et al*., 2019). It's worth noting that MCG differ from hybrid micro-grids (HMCG) in our classification because the former are made up of only one converter mechanism and rely on a single source.

On the basis of the energy source employed, the technologies are categorized as conventional, non-conventional, or hybrid. Conventional technologies run entirely on fossil fuels (usually diesel), whereas non-conventional technologies run entirely on renewable energy sources (RESs), (HMCG) run on a combination of sources (e.g. standalone solar PV with diesel generators) (Mandelli *et al*., 2016).

The unpredictability of renewable energy sources, particularly solar and wind necessitates the use of storage in non-conventional generation systems. Components that use potential energy (e.g. pumped hydro, compressed air), kinetic energy (e.g. flywheels), or chemical energy source (example H2 from fuel cells, batteries, etc.) are grouped into three categories (Mandelli *et al*., 2016). In rural areas of developing countries, rechargeable batteries storage device, and in some cases, they are also the primary electricity carrier (Diouf and Pode, 2015). HMCGs attempt to eliminate the need for batteries by combining diesel generators with renewable-based systems while limiting the size of the storage system (Mandelli *et al.* ,2016).

2.1. 4 Concept of Micro Grid and its Evolution of Electrical Power System

2.1.4.1 Concept and benefits of micro-grid system

There is no universal definition for either “mini-grid” or “micro-grid” power networks. In addition, the two terms are also used interchangeably to define same aspect (Comello *et al.*, 2017; Bhattacharyya, 2018). However, mini grids (MNG’s) are is considered to have higher capacity than micro-grids (MCG's) (Chris *et al*., 2015). These systems refer to the electric supply systems with loads and distributed energy (such as distributed energy resources (micro sources), storage devices plus controllable loads) that can be controlled and coordinated while hooked up directly to the main power grid or islanded. In addition, MCG's or MNG's may consist of power conditioning devices (Power electronic interfaces) common coupling point and cables.

MCG's have three major objectives/benefits (Motjoadi et al., 2020; Faisal *et al.*, 2018):

- To offer power quality and/or reliability and affordability (lower upfront expenses) that differs from the local standard of service, for example, to serve highly sensitive electrical loads such as emergency services, and to plausibly offer additional non - homogenous service to its internal loads
- To use local assets that are unlikely to be chosen or operated by the centralized grid, such as small-scale renewable resources or inter - connected plug-in electric car batteries for ancillary service.
- To introduce a controlled portfolio to the rest of the power system, such as to stabilize the grid from the variability of local renewable resources and loads.

Nonetheless, MCG's have three major hitches as follows (Faisal et al.,2018):

- MCG'S generate limited power
- MCG'S are created by energy sources such as solar and wind energy sources are intermittent in nature and unsteadiness in loads necessitating the installation of either large storage energy systems or dispatchable power sources such as DG's.
- Under abnormal conditions such as voltage swims, deviations in frequency and peak power time the MCG'S may fail to operate efficiently.
- The design and management of ever-growing power consumption of any MCG is complex.
- Demand side management is necessary for ensuring the generated electricity is equitably shared among the users during critical situations of power supply from MCG/ MNG.

Subsequent to the definition, merits and demerits related with MCG's, some aspects in relation with the structure of smart grid is also presented. At maximum level, smart grid consists of three parts which are outlined as follows (Hilorme *et al.*, 2019):

- Better functionality of the legacy high-voltage grid, for example, through the use of synchrophasors.
- Improved grid-customer interaction, for example, through smart metering and/or real time pricing.
- Previously unknown distributed entities, such as MCG's and effective distribution networks

2.1.4.2 Evolution of electrical power systems and historical perspective of Micro-grid systems

- The idea of the distributed generation or micro grid is not a new one. It was innovated by Edson in 1880's (Ramsebner *et al.*, 2021; Zhang et al. 2018). This type of power system is characterized by direct current (DC) power flow, comparatively miniature power stations, no power transformation; small distribution loops (no transmissions lines), lighting load was dominated by incandescent lamps and probably the DC motors for traction purposes. Similarly, around the same period in 1880's, Tesla introduced alternative of power generation characterized by alternating current (AC), huge power stations, possibility of voltage transformation, long transmission lines of electricity, lighting loads of incandescent lamps and induction electric motors (Ramsebner *et al*., 2021, Zhang et al., 2018). For more than a century, electricity generation, distribution, and consumption have depended on complex systems and economies of scale to supply electricity: large, fossilised fuelled or hydroelectric power plants generate electricity, and a complex distribution network, operated by professional grid experts, coordinates power supply to match demand. In the context of energy development, such a method faces challenges (Ramsebner *et al*.,2021; Zhang *et al*., 2018). It is sometimes impossible to expand the central grid quickly enough, aware of the severity of the issue of power access and the desire with which the global development society is approaching this issue. National grid expansion has been hampered in the past mainly by the financial hardships. Furthermore, trying to extend the larger grid to remote, rural communities may be prohibitively expensive (Ramsebner *et al*., 2021; Zhang *et al*., 2018). Remote and rural communities have traditionally relied on pollutant-laden diesel generators to meet their needs. Nowadays, micro-grids' potential has been unlocked around the world as the investment in renewable energy generation and battery energy storage has decreased

(Juanpera *et al*., 2022). Micro-grids are ideal for increasing energy access in rural and remote areas because they do not require a linkage to a larger grid (Juanpera *et al*., 2022). Simultaneously, the proliferation of cell phones has made micro grid expenses, functionality, and controlling easier than ever. Micro-grids have become the preferred option for expanding energy access in many contexts as a result of these factors. Micro grids normally work without connectivity to an external grid in a development context (Balderrama *et al*., 2021). They're small, standalone electricity systems that use local power generating resources to match local power supply and energy demand in general. A micro grid can be powered by any type of power production, from renewable energy sources for instance solar PV power to diesel. According to International Energy Agency (2017b), renewable energy RES's will power over 60% of new access by 2030 via off-grid and mini-grid systems .Micro grid technologies will provide electricity to the greater part of 1.1 billion users who do not normally have access to it in SSA region (Cotton *et al*., 2021). Rural micro-grids will benefit communities in those areas by substituting diesel generators and expanding the types of energy services available. Because of their flexibility in terms of designing and resource utilisation, these mini grids are thought to be the most cost-effective long term remedy for electricity access (Zebra *et al*., 2021). Off-grid and mini grid/ micro grid solutions powered by renewables now offer electricity to about 90 million inhabitants in African continent, demonstrating that the off grid electric grid has a larger role to play in achieving the SDGs' goals. These lead to improvements in health, the environment, social issues, and livelihood/economic opportunities (Bhattacharyya and Palit , 2021).

2.1 4.3 Types and applications of micro grid systems

(a) Types of micro grid systems

Micro grids can be classified into several groups (Shahab and Shahgholian 2021). Table 2.1 indicates categorization of MCG (Shahab and Shahgholian, 2021). A flexible micro grid must be able to import and export energy from and to the grid while controlling active and reactive power flows through energy storage management.

Table 2.1: Categorization of micro grid systems

Type of category of micro grid							
Operation	Application	Size	Architecture	Distribution system	Energy source	Distribution pattern	Scenario
Grid connectivity	Premium power	Small scale (Less than 10 kW)	Radial grid	DC micro grid	Diesel	Single phase	Residential
Handling the transient	Loss reduction	Medium scale(10 kW - 1MW)	Ring grid	AC micro grid	Renewables	Three phase	Industrial
Standalone	Resilience orientel	Large scale (More than 1 MW)	Meshed type	Hybrid micro grid	Hybrid	Three phase four wire	Commercial

Depending on the mode of operation, micro grid operating modes are widely recognized and defined as follows: Grid connected, transferred, or island, and reconnection modes, which enable a micro grid to improve energy supply reliability by disconnecting from the grid in the event of a network failure or poor power quality (Nazir *et al.*, 2021). Due to the lack of an infinite bus, the micro - grid should indeed sustain the reactive energy freely in the islanded mode (standalone) operation. In islanded mode, there are two major challenges: a) Maintaining the proper frequency and magnitude of voltage in the MCG; and b) maintaining power dynamic in the MCG (Hawkar, 2021).

Based on power distribution system, the MCG can be categorized as a DC electric network, an AC power network, or a hybridized energy system, each with its own set of benefits and drawbacks (Zebra *et al.*, 2021). There have been numerous studies on the benefits and drawbacks of both DC and AC MCG's. The DC MCG can be used in grid- connected or self-contained mode. A DC micro grid's distribution network might be one of three types: homopolar, bipolar and monopolar. In an AC MCG, all renewable energy sources and loads are connected to a common AC bus. The main disadvantage of the AC MCG's is the difficulty in the control and operation. As per the distribution system, AC MCG AC can be divided into three types: single-phase, three-phase three wire system, and three-phase four wire system. DC micro grids have higher reliability and efficiency, as well as the convenience of being connected to various distribution energy resources, when compared to AC micro grids (Shahgholian, 2021). The goal of installing hybrid micro grids is to improve the network's overall efficiency by minimising conversion stages, increasing reliability, reducing interfacing devices, and lowering energy costs (Shahgholian, 2021). In the various studies, there has been a lot of research on the applications, protection, and reliability of AC, DC, and hybrid micro grids. Table 2.2 shows the main differences between AC and DC micro grids according to distribution network (Shahgholian, 2021). Table 2.2 presents main differences between AC and DC micro grids according to distribution network.

Table 1.1: Tabl2 2.2: Main differences between AC and DC micro grids according to distribution network

Item	AC min-grid	DC micro- grid
The micro grid's energy quality	Low	High
Simplicity of energy storage management	No	Yes
Protection of the system	Components of protection are simple, cheap, and not efficiently established	Components of protection are complex, expensive, and well-established
Complicatedness/simplicity of electronic interfaces	Complicated	Simple
Number of electronic interfaces	High	medium
Control process of micro grid	Complicated	Simple
Devices functioning with the grid	Yes	No
External disturbance (stability)	External disturbances have an impact	Not influenced by external factors
Reconfiguration capability of existing facilities	Yes	No
Power converters in series connection	No	Yes

Additionally, the mini-grid avoids greenhouse gases and contributes significantly to climate emission reductions when renewable power technologies can be used for power generation (Zebra *et al*., 2021). Because such green MCG's/MNG's are not affected by fluctuations in fossil fuel prices, they can improve energy supply security. Mini-grids based on renewable energy can also make use of locally available resources that would otherwise be of limited economic value. However, their use in the generation of electricity can provide opportunities for local economic gains generation in the fuel delivery system, contributing to local economic development. As a result, mini-grids can be thought of as a reasonable option to the electricity access issue (Khirennas *et al*., 2021).

(b) Opportunities and challenges and of micro grid systems in developing countries

This section highlights the possible opportunities, challenges and the importance of the importance and implementation of rural electrification in developing countries as follows:

Opportunities*:* Despite the fact that grid extension is still the favoured way of electrification in many nations, it confronts a number of obstacles. Firstly, many countries' generating capacity is insufficient, and even urban regions are under-supplied. Rural users are unlikely to gain a reliable and high-quality supply at present grid electricity pricing, even if the system is extended. Secondly, grid extension is capital-intensive depending on the geographic location and remoteness. Given the financial hardship of many developing countries' utilities, it's easy to envisage grid expansion to rural areas not being high on their priority list. Thirdly, for developing countries with low level of electrification, for a long period of time the priority has been to connect the urban areas and peri urban locations, thereby overlooking the rural necessities to the future (Rabbi *et al*., 2021). A micro-grid/mini-grid can provide a solution in such circumstances.

Mini-grids, on the other hand, are up against stand-alone systems like solar house systems (SHS). Stand-alone systems can fill the void left by the grid, especially in locations with a dispersed population. The key constraint is the limited spectrum of deployment, the burden of maintenance on users, the lack of revenue-generating potential, and the considerably large cost of installation (Bhattacharyya, 2018). In general, these systems can only do a limited number of tasks, and direct consumption of electricity for economic development is limited. In addition, the consumer is responsible for system maintenance and component replacement when the warranty period expires. It is unrealistic to expect people in remote places to have the necessary knowledge and experience to maintain such modern devices on their own. Individual systems are typically expensive, and a comparable village scale infrastructure is likely to be less expensive than the totalized systems in a whole village (Bhattacharyya, 2018). Substantial economic gains and range can be acquired to give equivalent positive impact or even more enhanced. Therefore, micro/mini grids have a biggest opportunity to meet energy demand in the rural communities of developing countries (Bhattacharyya, 2018).

Challenges: The performance of renewable energy sources is influenced by a number of factors, none of which are constant over time. As a result, the micro grid’s performance, which is dependent on the role of these energy sources, is altered. Micro grids can enhance the reliability, quality, and security of traditional distribution systems, demonstrating that they are more reliable and useful method of generating electricity while reducing the use of non-renewable energy sources (Bhattacharyya, 2018). However, embedding approach of micro - grids into the main grid network can mainly pose a variety of technical and economic challenges. Some challenges of implementing micro/mini grid systems in developing countries faces are described as follows (Bhattacharyya, 2018):

(i) Limited expertise in terms of capability of generation, distribution and supply power to the isolated and rural areas, there practical complications.

(ii) High investments and business risks accompanied by various barriers such as locational restrictions, limited users of electricity, capability to pay, limited skills, etc.

(iii) Nature of the dispersed settlements in rural places provides difficulties to rural electrification (Low consumption does not convincing to invest)

(iv) Lack, ambiguous, and insufficient policies, socio- political influence, legal and regulatory (Good governance) framework for rural electrification in rural areas.

2.1.5 Renewable Energy Technologies

This part of the literature review section gives a description regarding the renewable energy technologies. The description about an introduction of renewable energy technologies and hybrid renewable energy-based micro grid system is provided as follows:

2.1.5. 1 Introduction of Renewable Energy Technologies

Based on incorporation of conventional and non-conventional of energy sources, hybrid energy systems can be grouped as hybrid energy systems with conventional technologies and hybrid energy system without conventional energy sources (renewable energy- based system). Each of these categories of hybridized energy systems can include distribution system to constitute mini grid/micro grid system (In either islanded mode or grid-connected mode) (Chava *et al.*, 2022). Therefore; this part of the discussion about the renewable energy technologies also includes the commonly used device (DG) and grid extension for rural electrification in developing countries (Chava *et al.*, 2022). Here is the description of renewable energy technologies:

2.1.5. 2 Conventional Energy Technologies

(a) Diesel generator: Batteries and many other energy storage devices are frequently used in autonomous systems, as well as diesel generators. The flow of direct current (DC) is generated by the solar PV panels integrated with batteries. Diesel engines, on the other hand, can power both continuous and alternating generators. Consumers frequently want alternating current; a discrepancy is then created between various structures depending on what type of electrical machine connected with the diesel engine. In addition, it should be noted that micro-turbines/gas turbines are also used as conventional energy source for power generator for rural electrification purposes.

(b) Power grid system: This is the popular method of generating power consumed globally using conventional energy sources such as coal, natural gas, mega- hydro power projects, etc. Most of the rural areas of the developing countries with connectivity of grid power do not use power from the main grids efficiently due to poor power quality, unreliability (blackouts, high power losses) and associated environmental concerns (Rajabet al., 2020) . The grid need to be supported by distributed generation.

2.1.5. 3 Biomass energy technologies

Figure 2.2 indicates **c**lassification of technologies of generating electricity from biomass energy (Osman *et al*., 2021).

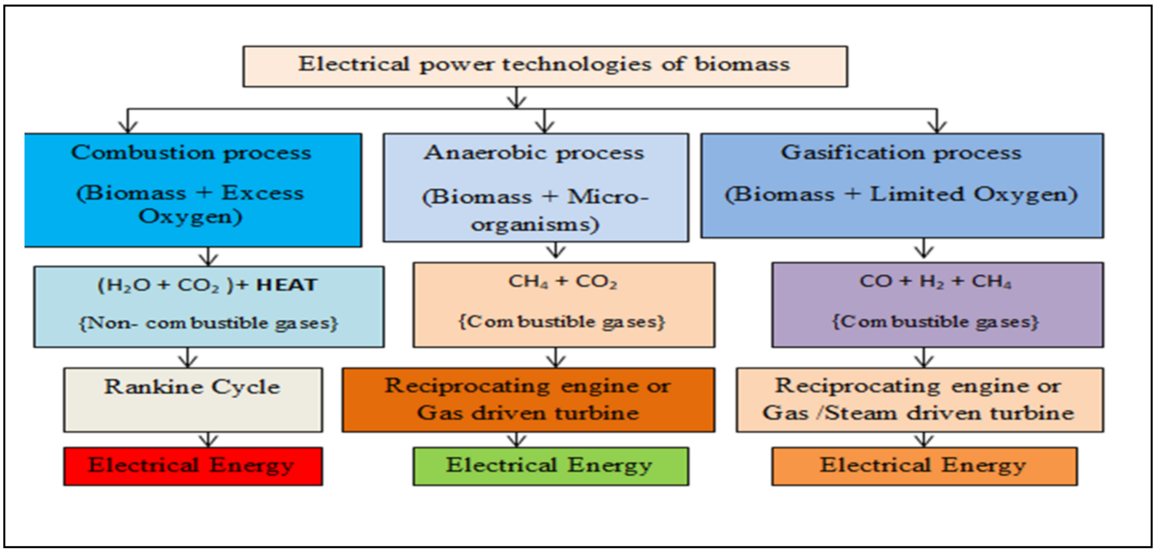


Figure 2.2. Classification of technologies of generating electricity from biomass

2.1.5. 4 Solar energy technologies

Solar energy can be used to generate electricity directly via PV cells or indirectly through concentrated solar power (CSP). They are as described below as follows (Khatibi *et al.*, 2019) :

(a) Photovoltaic cells (PV cells)

A PV cell is a device that uses the photovoltaic effect to generate an electric current. The PV effect is the creation of electrical potential electrodes placed to a liquid or solid system as a result of beam of light on it. A photovoltaic cell almost always has a PN junction between which a photovoltaic voltage is applied. The cost and efficacy of a photovoltaic (PV) cell are determined by the material used (Bagher *et al*., 2015). There has been a lot of research into finding the most efficient and cost-effective material for PV cells. The following are the requirements for an optimal solar cell material: The material used to manufacture the solar cells; the band gap should be around 1.1 and 1.7 electron volts (eV) (Dzhafarov ,2013); there should be a direct band pattern in the material, the material should be simple to get and non-toxic, should be able to be reproduced in huge quantities, the solar PV conversion efficiency of the material should be high, and a long-term stability should be present in the material.

The first generation cells are those built of crystalline silicon. Mono-crystalline or poly-crystalline silicon cells with high grain sizes may be used in these cells. They are the most popular PV cell type on the market. The mono crystalline silicon cells, which are built up of silicon positive &negative (Si p–n) junctions, have 25 percent efficiency. Polycrystalline cells are made by melting silicon and hardening it in order to align crystals in a specific direction, resulting in multi crystalline Si that is subsequently split into thin wafers. The polycrystalline cells have an efficiency of 20.4 percent. Although polycrystalline silicon cells have a lower efficiency than mono-crystalline silicon cells, this disadvantage is offset by cheaper production and a lower number of faults in the crystalline structure. In general, first-generation cells are more effective at lower temperatures and take up less space for the same amount of power. The fundamental problem of these PV cells, however, is that their functionality degrades as the temperature rises (Hayat *et al.*, 2019). ***Second generation of PV cells*** include thin film PV cells. They are less expensive than first-generation cells because they use less silicon material; but, due of their lower efficiency, they have a smaller market share. Thin film cells come in a variety of shapes and sizes. Amorphous silicon (AS) solar cells, for example, are synthesized on a substrate support after silane gas is decomposed in a plasma-enhanced chemical reactor. Because of their minimal material utilisation and the ability to produce modules roll to roll, AS cells are cost effective. Furthermore, Cadmium telluride (CdTe) solar PV cells, on the other hand, have a higher efficiency of around 17%. The cells can be made by chemically placing CdTe on a substrate and evaporating it. However, because these cells contain harmful ingredients and because tellurium generation is limited, they can be used indefinitely. Solar cells made of CIGS (copper indium gallium selenide) are more efficient than those made of AS or CdTe. The processing of elements such as Se, Ga, and Cu result in CIGS cells. At laboratory scale, these cells have 20 percent efficiency, whereas commercialized CIGS panels typically have efficiencies of 12 to 14 percent. The toxicity of these cells, as well as the rarity of the materials employed in them, are significant obstacles (Hayat *et al.*, 2019). ***Third-generation solar PV cells*** are obtained by the advancement over second-generation Photovoltaic modules in terms of environmental friendliness and efficiency. The inexpensive cost of the cells is its key selling point. When compared to second-generation cells, these cells are expected to reduce power costs by 50 to 80 percent. In order to enhance absorption, carrier production, and separation, these devices make use of the remarkable adaptability of quantum confinement and quantum dots nanostructures. Gyration technology can be used to combine quantum dots with liquids and apply them on the film. The most relevant third generation cells are organic solar (OS,) and dye sensitised (DS) solar cells. Efficiencies for both OS and DS solar cells are around 10 % (Hayat *et al*., 2019).

(b) Concentrated solar power (CSP) or solar thermal technologies (STT)

CSP or STT produces steam or hot air. This vapour or heated air is again used in a normal power cycle to generate energy. The following are the four forms of CSP technology now in use: power towers, troughs parabolic, dish/engine systems, and linear Fresnel reflectors (Hayat et al., 2019; Kaltschmitt *et al*., 2007):

- **Power towers**: The sun is tracked all day by heliostat distributed mirrors in this system. The sunlight reflected by these mirrors is focused onto a centrally located receiver on the tower. The receiver contains a fluid that collects thermal energy and then transmits it to the conversion systems, where it is turned into electricity. These power masts are outfitted with an energy storage system to provide a constant supply of electricity throughout the day. Water/steam is the working fluid in traditional towers, although contemporary towers are experimented with molten salts. The efficiency of a normal solar power tower ranges from 15% to 25%. Temperatures of these kinds of power range starting from 800°C to 1000°C (Hayat *et al.*, 2019).
- **Parabolic troughs:** Parabolic trough collectors, steam production or heat transfer system, rankine vapour turbine/generator cycle, and thermal energy storage system are basic components of a parabolic trough power plant (optional). An absorbent (working fluid), a transparent cover, and a parabolic reflector plate are the three main components of a parabolic trough collector. The heat leakage from the absorber tube is prevented by the concentric transparent cap. A solar tracking device is built into the parabolic concentrator. To receive the most solar energy, parabolic trough catchers follow the sun during the day. These sun rays are subsequently concentrated on an absorber tube situated at the collectors' focal point. The receiver pipe is a steel tube with a coating that maximizes absorbance in the wavelength range of the sun spectrum. To reduce heat loss, this metallic tube is placed within a glass tube. The

sun's concentrated radiation passes through the tubing (glass) and hits the absorber layer. This heats up the fluid in the pipe to the point where it generates steam, which is used to operate a traditional steam power plant (Hayat *et al*., 2019).

- ***Linear Fresnel reflectors***: A series of long flat or slightly curved mirrors are used in linear Fresnel collectors. These are positioned at various angles to concentrate sunlight on both sides of a permanent object. The receiver is a long tube which is coated with black chrome solar absorption cermet (an absorbent substance). The thermal energy is transferred to a normal electricity generation system by the fluid inside the tube, which is water/steam. Flat mirrors are less expensive than parabolic troughs in this type of arrangement (Hayat *et al.*, 2019).
- ***Dish-engine***: This is a Stirling dish system with a parabolic dish-shaped extractor which reflects direct sunlight onto a receiver at the dish's focal point. A gas turbine or stirling engine can be used as the receiver. The main benefit of the Stirling casserole technology is that the power generating unit is positioned at the dish's focal point, therefore no heat is lost due to heat transfer fluid. As a result, among the CSP technologies, the dish engine system is estimated to have the highest efficiency (about 30%) (Hayat *et al*., 2019).

2.1.5. 5 Small hydro power technologies

Hydropower generates the majority of the world's renewable electricity, accounting for 76% of total renewable electricity generation. According to the report of 2015 by the World Energy Council, installed hydropower capacity hit 1000 GW in 2013, accounting for 16.4% of globally, all power supply from all energy resources and 76% of renewable energy sources. China leads the world in hydropower installed capacity with 26 percent, followed by Brazil, the USA and Canada with 8.6%, 7.8%, and 7.6%, respectively. Globally, however, there is around 10000 TWH/year of underdeveloped hydropower potential for new development (Yah *et al.,* 2017). Hydro-power is the most dependable and low-priced renewable energy generation technology when compared to other renewable energy sources (Yah *et al*., 2017). Hydropower has the advantage of being able to be changed to suit base-load requirements while maintaining maximum capacity factor. It can also be used as energy input for any form of grid, including small, big, and isolated grids. Small-scale hydro-power is the most acceptable solution for generating electricity for remote places in underdeveloped countries like Tanzania (Yah *et al*., 2017). Small-scale hydropower has the potential to replace a significant amount of fossil-fuel fired electricity systems. Furthermore, if executed correctly, small-scale hydropower might have a lower environmental and social impact. Small hydropower plants, on the other hand, can have almost the same repercussions as bigger hydropower plants if they are poorly implemented, independent of the society's needs. Small-scale hydropower is defined differently in different nations for legislative and administrative purposes. According to the World Small Hydropower Development Report, the global potential for small hydropower is estimated to be around 173 GW. Because some organizations discourage countries from establishing large-scale electricity generation due to environmental and socioeconomic issues, small hydropower will play a larger role in global power generation in the future. Various authorities have used different boundaries to classify hydro-power facilities depending on their capacity. However, hydro-power plants can be classified based on the amount of electricity they generate. Large scale hydropower plants can create above 100 MW. Mini hydropower plants can generate between 100 kW and 1 MW of energy and can be either stand-alone or grid-connected while small scale hydropower plants can produce less than 30 MW of energy. Micro-hydropower, on the other side, can generate electricity in the range of 5 to 100 kW. Pico-hydro is the smallest small-scale hydropower system, with a maximum output of 5 kW (Yah, *et al*., 2017).

As previously stated, large-scale hydro power plants necessitate the construction of dams, whereas smaller hydro power plants rely on direct river flows. The primary grid receives electricity generated by large-scale hydroelectric units. Small-scale hydropower generators, on the other hand, are typically employed for rural and off-grid purposes. It has also been demonstrated that it can generate power and that it can be used in any place with a low water head. This technology is not only cheaper but also offers an environmentally liable solution for electricity generation. Furthermore, it may be a solution to home and commercial users' energy demand difficulties. The turbine's power production is also affected by the wheel's dimensions, as well as the water's speed and flow rate.

Hydro-power generators can also be categorized depending on the size of the plant and the type of scheme in addition to their power output capacity. There are three types of hydropower plants based on their size: impoundment, diversion, and run-of-river (Yah *et al.* , 2017). The water collected in the reservoir is used to generate energy in an impoundment. Typically, large-scale hydropower plants are involved. The technology may or may not necessitate the development of dams to hold water in a diversion type. However, it makes use of a diversion facility that diverts river water through a penstock or canal. The third form is run-of-river (ROR), which relies on natural water flow at nearly zero head and needs little or no reservoir. The RoR schemes are classified as follows: (a) diversion with no storage (diversion weir scheme), (b) non- diversion without water storage (dam-toe RoR scheme), and c) diversion with water storage (pondage scheme) (Yah *et al.* 2017; Kuriqi *et al.*, 2021). In many poor countries, small hydropower is gaining appeal. The majority of turbines need a static head about 10 metres or more though some can run at 3 metres. In general, small-scale hydropower technologies are more favourable than large-scale hydropower plants, because large-scale hydropower facilities have a negative influence on the environment as a result of the land taken to build the plant (Kuriqi *et al.*, 2021). Furthermore, hydropower reservoirs have a number of disadvantages, including land loss, animal and human relocation, ecosystem disruption, methane emissions, and safety problems *(Yah, et al.*,2017).The potential of hydropower, mechanical energy, and the turbine's testing efficiency can be calculated as follows equation (2.1): potential of hydropower, mechanical power, and turbine's experimental efficiency (Yah *et al.*, 2017).

$$\begin{cases} P_h = \rho g h q \\ P_M = T_W \\ \acute{\eta} = \frac{P_M}{P_h} \end{cases} \qquad (2.1)$$

where P_h is the theoretical power available in the water (Watt), ρ is the density of water (kg/m3), g is the acceleration due to gravity (m/s2), h is the effective pressure head of water across the turbine (m), Q is the flow rate passing through the turbine (m3 /s), P_M is the mechanical power output produced by the turbine (Watt), T is the torque produced by the shaft (N. m), ω is the rotational velocity (rad/s), and η is the hydraulic efficiency of the turbine. The following formula (2.2) can be used to calculate annual energy generation in kilowatt-hours (Yah *et al.*, 2017):

$$E_{Annual} = Installed\ capacity\ \ in\ kW\ \times 8670\ hours\ \times Capacity\ factor \qquad (2.2)$$

The capacity factor is supposed to be the system's efficiency while operating under actual working conditions. It's the ratio of average output to installed capacity for a certain time period. The most efficient method to generate electricity is still through hydropower *(*Yah *et al.*, 2017). Modern hydro turbines may convert up to 90% of available energy into electricity, though this decreases as the size of the turbine increases.

2.1.5. 6 Geothermal technologies

The concentration of geothermal energy industry is for electricity generation. The use of geothermal (conventional, unconventional and advanced technologies) demonstrates how diverse and multi-faceted the geothermal sector has become, with temperatures ranging from 7 degrees Celsius to over 350 degrees Celsius: Following is the description of the geothermal technologies:

Traditional geothermal technologies are geothermal electricity technologies (Conventional geothermal technologies): High temperature, high enthalpy, or hydro-thermally derived geothermal plants are all terms used to describe conventional geothermal power. Dry vapour, flash steam, and closed-loop/binary geothermal plants are the three types of conventional hydrothermal geothermal plants (Ball, 2021; Kurnia *et al.*, 2022). Distinct power plant layouts have different environmental, GHG emission, cost, energy conversion efficiency, and operating requirements (Ball, 2021).. For instance in 2016, the installed capacity of flash steam cycle facilities accounted for 41%, dry steam for 23 percent and double steam flash for 19% of the total installed capacity. Closed-loop/binary accounted for only 14% of the total installed capacity. Triple steam flash, binary/flash hybrid, and other technologies account for the remaining 3% of power plants (Ball, 2021). Figure 2.3 indicates three types of conventional hydrothermal geothermal plants.

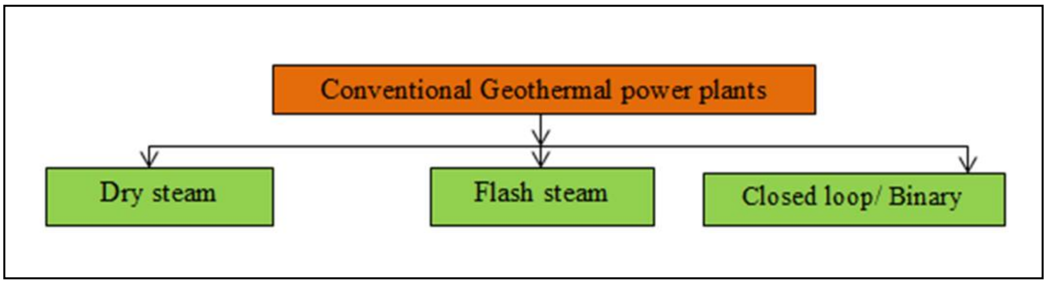


Figure 2.3. Types of hydrothermal geothermal plants (Source: Author)

Closed-loop district power systems are also being developed; traditionally, they have been utilized for circulating the geothermal brines through a network of residences to provide water for heating and cooling. Closed-loop/binary development now accounts for a minor portion of global geothermal development. This organic rankine cycle (ORC) is a significant technology in the power plants. The closed-loop/binary geothermal power plant increased the geographical footprint of the US sector by allowing access to lower temperature hydro-thermal resources for electricity production. Importantly, the technology not only delivers geo-thermal brine to the surface, but it also ensures that it does not contact with the environment, lowering GHG emissions. Because heat is extracted from hydrothermal waters using a working fluid, caustic brines do not erode metal sections of the power plant. When discussing the implementation of ORC technology in geothermal applications, it's important to remember that this technology isn't unique to the geothermal business. In fact, ORC equipment is used to "repurpose heat" in a variety of industries, including solar, geothermal, biomass, and reclaimed or waste heat from gas and coal power plants (Ball , 2021).

- ***Low-temperature geothermal technology***: is a type of geothermal technology that has been available for a long time. The GHP (geothermal heating system) or GSHP (ground source heat pump) and district energy systems are the two most important technologies in this category. In 2019, the entire residential and business sectors in the United States utilized almost 21 quadrillion British heat units, accounting for 28 percent of total end-use energy consumption in the country. As a result, GSHP and central heating might play an important role in decreasing emissions. Depending on the latitude, local temperature, and season, the GSHP can be used for heating or cooling.
- ***Un-conventional geothermal technologies:*** Enhanced geothermal systems (EGSs): These systems are categorized as un-conventional geothermal technologies because, at their most basic level, they work through constructed or engineered fissures, effectively using fracking techniques. An ORC/ a flash or binary arrangement can be used to finish the above ground transformation from heat to electricity. Based on the temperature, the EGS geo-thermal system can be used to produce direct heat or power (Casey, 2018).
- ***Advanced low enthalpy geothermal technologies:*** For electric power generation, low enthalpy or temperature geo-thermal in the 110–150 °C range has been examined at depths lower than 3 km (Casey, 2018).
- ***Advanced super-critical geothermal technologies:*** Several high-temperature demonstrations have emerged within the geothermal energy industry, all these programmes aim to identify new and cost-effective techniques to extract super-critical heat (>350 °C) for geo-thermal electricity generation(Casey, 2018).

2.1.5. 7 Wind energy technologies

Wind energy is a promising renewable energy supply that is also environmentally benign (Dawoud, 2022). Wind, on the other hand, is difficult to foresee due to its unpredictability in terms of direction and speed. Wind energy can be extracted in two forms: mechanical and electrical. The rotor or wind turbine, which captures the energy from wind and converts it into mechanical energy, is one of the most essential devices in the wind power conversion system. Electricity can be extracted by converting mechanical energy into electrical energy with the use of an electrical generator. According to estimates of global wind resources, there are five basic types of wind resource potentials: Site, meteorological, financial, technical, and operational potential. Wind resources may be present but insufficient for site possibility of generating electricity due to its geographical effects of the site on power generation, according to meteorological potential. The economic, technical, and operation capabilities of wind turbine system are all influenced by the location chosen (Musial *et al.*, 2006). In addition to site selection based on meteorological data, viable technologies and competitive pricing must be considered, as well as temporal limits on incentives for wind capacity. The economic, technical and implementation capabilities of a wind turbine system are all influenced by the location chosen. In addition to site selection based on meteorological data, relevant competitive and technologies costs should be assessed, taking into account the limits to and motivations for wind generation capacity within a specific time frame (Huenteler *et al*., 2018).

The decision to adopt axis rotation orientation is based on the possibilities of the site or geographic area. The upward pivot wind turbine (VAWT) is portrayed by being autonomous of wind course; henceforth, using wind from all bearings , conversely to the flat hub wind turbine (HAWT), which uses wind from a specific heading (Su *et al*., 2021). The fact that needs to be viewed as makes furthermore, the application type, i.e., inland, seaward, building coordinated, and distant regions, one more element. For HAWT determination, numerous boundaries are thought of, for example, power limit, tower stature, edge length, structure support (particularly for seaward establishment, and kind of generator. Separating between the pinnacle stature and the cutting edge length is significant for power limit and the levelized cost of energy (LCOE). At the same time, the condition of wind speed, assuming it is consistent or variable, is significant for the sort of generator and power electronic converter utilized for the WT type. Moreover, the choice of appraised breeze speed is the main element for the breeze energy framework and ought to be founded on the advancement of energy creation and cost by the LCOE from one side and limit factor from the opposite side.

(A) Types s of wind turbine

Wind turbines (WTs) are chiefly arranged in light of the directions for the hub of turn, kind of generators, speed of revolution, and the control activity utilized. The ideal blend of these components for a particular WT is generally conveyed out as per the particular area attributes. For example, in metropolitan regions where the chance of choppiness is high because of tall structures and hindrances from trees limiting the development of air will make tackling of energy from the breeze very troublesome; thus, how much energy prone to be created is exceptionally subjected to the sort of utilized WT.

(a) **Horizontal axis wind turbine (HAWTs)**

HAWTs are the most common form of wind turbine, especially in metropolitan areas. They are highly recommended since even on a little scale, they are likely to be more efficient. The blades' rotational axis is horizontally positioned. The power in the wind is converted to rotating shaft energy by the flow of the air through the blades. With a yaw motor, a propelling type of rotor is positioned directly on the horizon plane and continuously steered towards the wind. One, two, three, or even more blades can be found on a propelling type rotor. The rotor rotates faster with fewer blades, requiring greater structure support for the WT system having blade rotor system being the most effective rotor design. HAWTs are responsive to wind direction and speed; as a result, when the wind direction changes or there is any type of barrier, the performance of the HAWT is likely to suffer, particularly in an urban setting. The HAWT's additional restrictions are related to the dangers it poses to birds and aviation. Due to their height, maintaining the turbines, as well as manufacturing and installation costs, it is always a difficulty to implement them. The HAWT's big blades pose another issue, as they are not ideal for all environments, particularly in towns and cities (Su *et al.*, 2021).

(b) **Vertical axis wind turbine**

The upward pivot wind turbines (VAWTs) are intended to permit the turbine's edges to turn in an upward way. The value of these sorts of turbines is that there is no need for any yaw instrument to situate the turbine in the breeze heading, consequently making them ideal for metropolitan applications. Likewise, the establishment of the gearbox and the generator is more straightforward, since these parts are frequently situated nearer to the outer layer of the ground. These attributes additionally guarantee that any upkeep can undoubtedly be done. The plan of the VAWTs makes them additionally appropriate for creating energy at a limited scale much under tempestuous circumstances and shifting breeze speed contrasted with the HAWTs; this fact upholds the justification for their high application in metropolitan networks across the globe (Su *et al.*, 2021).

The energy delivered utilizing the VAWT is commonly utilized at a similar age area. VAWTs are great for limited scope purposes, as the energy got is not exactly that from the HAWTs (Rajpar *et al.*, 2021). The use of a VAWT, particularly in metropolitan regions, keeps increasing because it is not difficult to introduce and less expensive than different sorts. They can without much of a stretch be scaled to a size and can be introduced at a height nearer to the ground surface. Also, their impact on birds and airplane is lower. These variables are contributing reasons prompting an increment in the portion of the overall industry for these kinds of turbines.

2.1.5. 8 Tidal and wave technologies

Oceans are a great source of renewable energy that is stored as thermal (heat), kinetic (waves and tides), chemical (chemicals), and biological (bio-energies) energy (biomass). Kinetic energy is harvested by the flow of tidal current or wave generators, while salinity and temperature gradients are harvested by saline power stations and thermo-electric generators. The fall and rise of sea and ocean waters are used to generate tidal power (Khan *et al*., 2017; Zhang and Ma, 2022) . Neap and spring tides with a range of 4–12 m have a capacity of 1–10 MW/km around the seashores. Gravitational fluctuations on Earth and in space have predictable effects on power generation capacity. Due to the earth's misalignment with the sun and the moon, high tides (spring tides) occur on new and full moons, and neap tides (little tides) occur in waxing and waning half-moons. The Earth spins at 16,500 kilometres per hour and orbits the sun at 107,000 kilometres per hour (Khan *et al*., 2017).

(a) Tidal energy

Tidal power generation sites, like coal, oil, gas, shale, and mineral reserves, are found naturally along the sea and seas. An estuary on the seashore can be used to determine the potential for tidal power generation (Zhang and Ma, 2022) . The energy potential is provided by if the springtime tide has an estimated level of R metres above the sea datum line, produced energy is defined in equation (2.3) as follows (Khan *et al*., 2017):

$$e_{tide} = \int_{h=0}^{h=R} hAd\mathrm{h} \qquad (2.3)$$

Where ρ is ocean water thickness (kg/m2), g is gravitational consistent (9.81 m/s^2). The energy related with a proper region estuary might be expressed as follows (Khan *et al*., 2017):

$$e_{tide=} \ 0.5\,\rho g A R^2 \qquad (2.4)$$

Considering, $\overline{P_{tide}} = \frac{e_{tide}}{Time}$, (as average value), it becomes

$$\overline{P_{tide}} = \frac{0.5\,\rho g\,R^2}{Time} = 1025 \times 9.81 \times A \times \frac{R^2}{44700} = 225A\,R^2 \qquad (2.5)$$

Where, 44,700 presents a time in seconds which is equivalent to 6 hours plus 12.5 minutes. If there should be an occurrence of a twofold cycle flowing station creating power in forward and invert headings of water streams then the power likely increments to 450AR^2 kW two times of the single cycle station follows (Khan *et al*., 2017). Assuming the flowing reach equivalent to contrast of greatest and least levels in the bowl, then, at that point, at a normal water release rate (Q =AH/t) through the turbine the work done by falling water through h stature is given by is expressed in equation (2.6) as follows (Khan *et al.*, 2017) :

$$P_{tide} = \rho Q h \qquad (2.6)$$

The capacity of tidal power generation improves as the tidal range and minimum barrage, dam, or dyke is increased. A channel, an estuary, creek, rut, or runnel near the seashore can provide adequate storage. The barrier, which forms a basin or estuary, sluice gates, which fill or empty basins, and turbines, which mechanical energy is created by conversion kinetic energy, which can then be transformed into electricity by coupling generators, are all key parts of tidal power stations. In order to withstand water waves, the dyke's crest and slopes are made of rock infill. Local and remote operated gates are placed on the sluice gates. To withstand saline water, sluice gates can be made of steel (Khan *et al*., 2017)

(b) Wave energy converters (WEC's)

Winds cause water waves to form on the ocean's surface. Near the seashore, these water waves are 1.32 m to 6 m high, and deep ocean waves are several metres high. The height of a water wave is determined by the ocean's depth. Along the seashores, huge energy fluxes are available. Wind energy is turned into water waves that are thinly scattered throughout the oceans in all directions. Wave farms have a greater energy density than solar power plants (0.1 to 0.2 kW/m^2) and wind sites (0.4–0.6 kW/m^2). Kinetic and potential energies are both present in ocean waves. In the vertical direction, the wave amplitude $2a$ fluctuates in a sinusoidal way from crest to trough. The intensity of a position on a wave can be stated in the equation (2.7) as follows: (Khan *et al*., 2017) :

$$y = a\,sin\,(\frac{2\pi x}{\lambda} - \frac{2\pi t}{T}) \qquad (2.7)$$

It can be re-written 2/=M and 2/T=N by assuming 2/=M and 2/T=N.

$$y = a \sin (M * x - N * t) \tag{2.8}$$

Where t is the time in seconds, T is the period, and is the wavelength. The wave's potential energy can be determined using equation 2.9 (Khan *et al.*, 2017):

$$Pe_{wave} = 0.5\, g * \rho * B * y^2 * dx \tag{2.9}$$

Substituting (2.9) for (2.10) yields:

$$Pe_{wave} = 0.5\, g * \rho * B \int_0^{\lambda} a^2 sin^2\, (M * x - N * t)\, dx \tag{2.10}$$

When equation (2.10) is integrated at t=0 and the area of the wave A=B is applied, (2.10) may be written as:

$$Pe_{wave} = 0.25 * g * \rho * A * a^2 \tag{2.11}$$

Wind flows across the ocean surface give water waves kinetic energy. A water wave's kinetic energy can be calculated using equation (2.12) (Khan *et al.*,2017):

$$Ke_{wave} = 0.25 * g * \rho * B * a^2 * \lambda = 0.25 * g * \rho * a^2 * A \tag{2.12}$$

Water wave energy is the total of kinetic and potential energies that can be extracted using wave energy converter (WEC) that oscillates and pitch. The sum of the two kinds of energies is expressed in equation (2.13) (Khan *et al.*, 2017)

$$Et_{wave} = 0.5 * g * \rho * B * a^2 * \lambda = 0.5 * g * \rho * a^2 * \lambda * A \tag{2.13}$$

The wave power ($P_{wave} = \frac{Et_{wave}}{t} = Ef$)) can be calculated using expression below (2.14) (Khan, Kalair et al. 2017):

$$P_{wave} = 0.5 * g * \rho * B * a^2 * Af \tag{2.14}$$

The Scripps formula can be used to calculate wave height in relation with the wind speed (U) using equation (2.15) below (Khan *et al.*, 2017):

$$H = 0.085\, U^2 \tag{2.15}$$

The Zuider Zee formula relates the wave height to the sea/ocean depth (D), the inclination in between wind and fetch (θ), un-obstructed fetch (F), and the constant K ($6.08 * 10^{-3}$) as follows in equation (2.16) (Khan *et al.*,2017) :

$$H = \frac{K* U^2 * F * Cos\ \theta}{D} \tag{2.16}$$

The small amplitude wave theory can be used to study the general behaviour of ocean waves. The wavelength of an ocean wave is equal to CT, where C represents the wave's speed (celerity). According to the low amplitude wave motion, the wave celerity for deep ocean waves will be $\sqrt{\frac{g\lambda}{2\pi}}$. Following that, the wavelength can be defined as in equation (2.17) (Khan *et al.,* 2017):

$$\lambda = CT = 1.56 * T^2 \tag{2.17}$$

The intensity of wave power (kW/m) transferred at a straight angle is given as follows in equation (2.18) (Khan *et al.*, 2017):

$$P = 0.96 * H^2 * T \tag{2.18}$$

Wave power can be obtained for about 90% whereas solar and wind energy are only available 20–30% of the time. Water waves have the ability to travel large distances with minimal energy waste.

. (c) Ocean thermal energy converters

Ocean thermal energy converters (OTEC), Ocean thermo-electric generators (OTEG), and salinity gradient osmotic power plants can capture ocean thermal energy at sites where rivers meet the sea. Over land masses and ocean waves, the sun beams evenly. The sun is reflected by glaciers, but it is absorbed by the oceans, which heats the water. Because the seas cover more than 70% of the world, they absorb solar energy comparable to 250 billion barrels of oil. The annual power produced by OTEC systems in the ocean is projected to reach 30 TW (Khan *et al.*, 2017).

(d) Ocean thermo-electric generators (OTEG)

To generate usable electricity, ocean thermo electric generators (OTEG) require a temperature difference of at least 100 degrees Celsius. Incinerators employ TEG’s to converting waste heat to electrical energy. They're also utilised on poles to translate a big negative temperature differential between ice (0 °C) and air (50 °C), which is twice as hot as the maximum ocean temperature. They can also generate power from focused solar energy. In the case of ocean energy, OTEGs could be utilised by coal power plants to transform waste energy into electrical energy and by subsea oil wellheads to operate underwater instrumentation. The difference in temperature between the sea/ocean floor water and the deeper well head is large enough to drive thermo-electric generators (Khan *et al*., 2017).

2.1.6 Renewable Energy Technologies Hybrid Renewable Energy-Based Micro Grid System

One of the cleanest kinds of energy conversion is from wind and photovoltaic power sources. One of the benefits of combining different sources is that it can deliver sustainable electricity to locations that aren't served by the traditional power infrastructure (He *et al*., 2018) . They are widely utilized in a variety of applications, but because of their non - linearity, hybrid energy supply systems have been proposed to address this issue with significant improvements. Generally, hybridization entails integrating many energy sources and storage units into a single system in order to improve energy production and control (He *et al.*,2018). Hybrid renewable energy supply systems (HRESS’s) or multi-source multi-storage systems - abbreviated as MSMSSs - are the terms used in review papers to describe them (He *et al*., 2018).

A hybrid power system's goal is to generate as much electricity as feasible from RES's while meeting load demand. A hybrid system may also include a distribution system (mini-grid/ micro grid system), an energy storage system, converters, fillers, and a load management control or monitoring system in addition to energy sources. All of these items can be interconnected in a variety of ways (Bertheau ,2020). Depending on the scale of the system, renewable energy sources can be connected to the DC -bus. A HRESS's output power can range starting from just few watts for home uses to some mega-watts for systems used to electrify small villages.

2.1.7 Merits and Demerits of a Hybrid Electric System

Hybrid renewable energy systems (HRESS's) are appealing combinations utilized for various purposes including rural electrification, water pumping, and telecommunications. The most appealing features of power generating approaches are their ease of use and independence from a single energy source, allowing them to work both during the day and at night. On the other hand, the drawback is that the system is more sophisticated in a comparison with a single-source system because there are required several sources and energy storage units. An energy management system is used in this scenario. Control is required to manage the power flow, resulting in a more stable power system, sophisticated, and of course, maybe more expensive.

2.1.8 Hybrid Electric System Configurations

A power system designer's first and most fundamental decision is which kind of architecture to adopt. This choice will have an impact on all other parts of the system's design, including all the types and numbers of power converters required. As a result, there are two options to consider which are power converter and common bus type selections. There are three choices of the hybrid configuration, that is, with architecture of DC bus, AC, and AC/DC bus (Syed and Morrison, 2021). Figure 2.4 depicts typical configuration of the hybrid system with AC bus and DC bus. In comparison to prior configurations, it performs better. Renewable energy is used in this scenario and diesel fuelled generators can convert a part of the load to AC directly, improving system performance while lowering the diesel generator's power rating of the inverter. By synchronizing the output voltages of the diesel fuelled generator and the inverter, they can work independently or in parallel. Located between two the buses, converter (rectifier & inverter) can be substituted by a bidirectional converter, which conducts the DC/AC conversion (inverter operation) in normal operation, supply the peak load when diesel generator operates at its maximum capacity (Syed and Morrison, 2021; Bhattacharyya and Palit 2014).

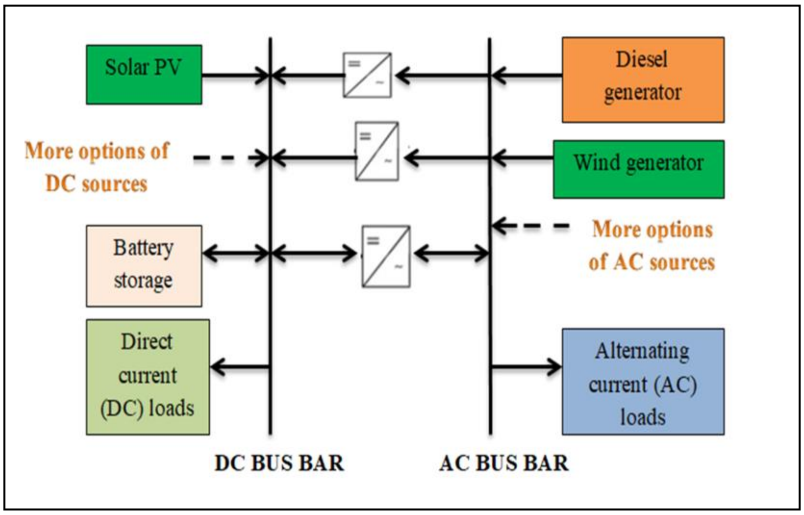


Figure 2.4. Typical configuration of the hybrid system with AC bus and DC bus

The following are some of the benefits of this configuration (Bhattacharyya and Palit, 2014):

- The DG and inverter can run in simultaneously or separately. When the load is low, single or both of them can create the required energy. During high loads, both sources can run in parallel.
- The ability to reduce the DG's and inverter's nominal power capacities without impacting the system's ability to serve peak demands.

The downsides of this configuration are presented as follows (Bhattacharyya and Palit, 2014):

- Because of the parallel performance, the inverter must be able to work autonomously and with output voltages synchronized with the output voltages of the diesel generator) and of course the design of this system is relatively complex.

Similarly, a power converting mechanism (Simply called converter) is a system for adjusting the source of electricity to a particular receiver by transforming it.

Note: The hybrid system's power output might range from a few watts for home applications to a few mega-watts for systems used to electrify remote islands. As a result, for hybrid energy systems with a capacity < 100 kW, the AC and DC bus architecture with battery storage is the most common (Bhattacharyya and Palit, 2014). To be able to serve the average load for a couple of days, the storage system employs a large number of batteries. Little renewable energy sources are connected to the DC bus in this hybrid system. Another option is to use inverters to convert continuous electricity to alternate power. Hybrid systems that are utilised for applications that require relatively little power (less than 5 kW) typically serve DC loads (Bhattacharyya and Palit, 2014). Low power hybrid systems are used for autonomous systems such as telephone stations and pumping stations systems; average power hybrid systems are used for micro-isolated systems such as powering a village; and large power hybrid systems are used for isolated systems such as islands (Bhattacharyya and Palit 2014).

2.1. 9 Energy Storage Systems in the Micro Grid System

One of the most important factors is energy storage. It has the potential to reduce power fluctuations, improve system flexibility, and allow the storage and delivery of electricity produced by intermittent renewable energy sources like wind and solar. With wind energy systems or hybrid wind systems, many storage technologies are utilized. It can be mechanical, chemical, electro-chemical, and electrical (Bhattacharyya and Palit, 2014). The following graph summarizes the most commonly used storage technologies. Super-capacitors are based on the separation of chemically charged species at an electrified interface between a solid electrode and an electrolyte. Super-capacitors are fundamentally based on the dissociation of chemically charged species at an electric link between a solid electrode and an electrolyte (Bhattacharyya and Palit, 2014). Capacitors are defined as the physical separation of electrical charge through a dielectric medium, while super -capacitors are defined as the division of chemically charged species at an electric link between a solid electrode and an electrolyte. However, fuel cells and batteries work by converting chemical energy to electrical energy (Bhattacharyya and Palit, 2014). Figure 2.5 presents categories of energy storage system.

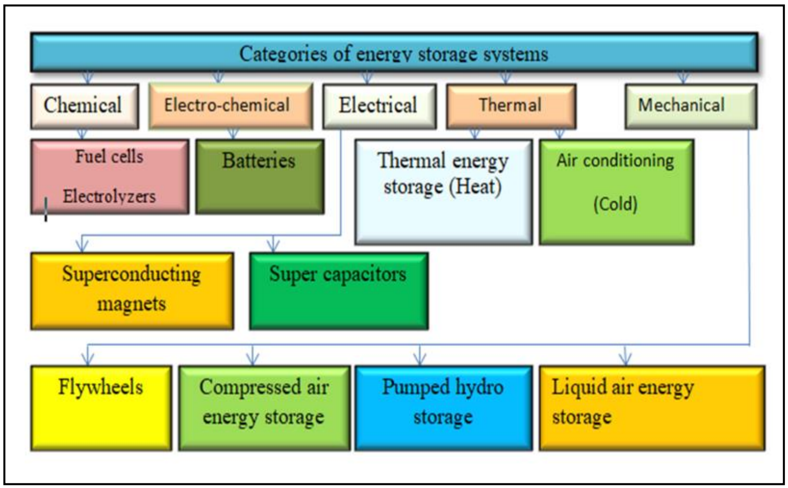


Figure 2.5. Categories of energy storage system

2.1. 9. 1 Electrochemical Energy Storage Systems

Most stand-alone applications necessitate the use of batteries. Lead acid, Li-ion, and hybrid flow batteries are the most prevalent battery types utilized for storage in renewable energy systems. Due to their high performance, lead-acid battery storage systems are widely utilized for traction in PV, wind turbine, and hybrid systems, as well as micro grids and off grid systems. For high-power mobile applications, lithium-ion batteries are the best alternative. Flow batteries, on the other hand, may store energy for longer periods of time than lithium-ion batteries (Bhattacharyya and Palit, 2014).

2.1. 9. 2 Mechanical Energy Storage Systems

(a) **Electric flywheel energy storage systems**

A cylinder with a shaft coupled to an electrical generator makes up flywheel electric energy storage. The generator converts electrical energy into kinetic energy, which is saved by raising the spinning speed of the flywheel (Bhattacharyya and Palit, 2014)l. The stored energy is transferred to electric energy by the generator, which slows the revolving speed of the flywheel. Storage costs are still a major economic constraint for wind-only applications. Power storage in wind turbines can be accomplished in a variety of ways. Inertial energy storage, on the other hand, adapts well to abrupt power surges (Bhattacharyya and Palit, 2014). Furthermore, it enables the acquisition of very interesting information. When it comes to storing and delivering power, the power-to-weight ratio is important and is expressed in equation (2.19) (Bhattacharyya and Palit, 2014).

$$P_{REF} = P_L - P_{WIND} - \Delta P \tag{2.19}$$

Where, P_{REF} symbolizes reference power, P_L denotes load power, P_{WIND} represents wind power, and ΔP stands for the power needed to keep the DC voltage (v_{DC}) at fixed value.

Energy reference for the flywheel is determined in equation (2.20) as follows:

$$E_{C,REF} = E_C^{T_1} + \int_{T_1}^{T_2} P_{REF}\,\mathrm{dT} \tag{2.20}$$

Where $E_C^{T_1}$ stands for preliminary energy.

The speed used as a benchmark of flywheel is determined as follows in equation (2.21) (Bhattacharyya and Palit, 2014):

$$\Omega_{S,REF} = \sqrt{\frac{2.* E_{C,REF}}{J_T}} \tag{2.21}$$

Where, $J_T = J_{FLYWHEEL} + J_{IG}$

Flywheel energy storage system (FESS) can suppress fast wind power variations in a wind power conversion system (WPCS). The WPCS based on an induction generator is modelled in this paper. An induction generator, a wind turbine a rectifier/inverter, and an FESS make up the system (Bhattacharyya and Palit, 2014). Even if the speed varies, the device's aim is to give consistent power to the load connected to the rectifier/inverter. This is mostly accomplished by maintaining a steady DC bus voltage. As long as the wind power is sufficient, the flywheel energy storage device helps to keep the supplied power to the load constant (Bhattacharyya and Palit, 2014).

(b) **Pumped hydro energy storage system (PHESS)**

A pumped hydro system with two big storage tanks/sources (upper and lower), an electrical machine (motor-generator), and a reversible pump–-turbine set make up a pumped hydro energy storage system (PHESS) system. Due to its fundamental characteristics, it is seen as an appealing solution for energy storage system (Bhattacharyya and Palit, 2014).

(c) **Super-capacitors energy storage system (SCESS)**

Electric double-layer capacitors, also known as super capacitors (SC), electro-chemical double-layer capacitors (EDLCs), or ultra-capacitors, are a type of electric double-layer capacitor (Bhattacharyya and Palit, 2014). To improve the capacitance, they use polarized liquid layers between the conducting ionic solution and the conducting electrode. They allow for a significantly higher energy density, as well as a high power density; however the voltage fluctuates depending on how much energy is stored. SCESS's are employed in wind energy conversion systems to reduce fast wind power variations over a short time range. As a result, they can only be thought of as a backup for wind turbines, and they are usually paired with a battery energy storage system in a hybrid energy storage system (Bhattacharyya and Palit, 2014).

(d) Fuel cells

There are six most commonly used types of fuel cells are such as proton exchange polymer membranes fuel cells, direct methanol fuel cell, phosphoric acid fuel cells, Solid oxide fuel cells (SOFC) and molten carbonate fuel cells (MCFC) (Bhattacharyya and Palit, 2014). Polymer electrolyte fuel cells have dominated the transportation application since their invention. They have a low operating temperature and a quick start time (Bhattacharyya and Palit, 2014).

2.1.10 Electrical Loads and Demand Management Response in Micro Grid System

Micro grid energy management is a difficult problem for micro grid operators (MGOs) because of the prevalence of energy storage mechanisms, renewable energy sources and demand response in micro grids (Murty and Kumar, 2020). A micro grid system contains a variety of loads, and each one is critical to its operation, stability, and control. A static load or a motor/electronic load is two types of electrical loads. The micro grid can power a variety of electrical loads (such like residential or industrial) that are considered sensitive or important and require high levels of reliability (Murty and Kumar, 2020). This type of operation necessitates numerous considerations, including giving precedence to key loads, improving power quality delivered to particular loads, and improves operational efficiency (reliability)for pre-specified load categories. Local generation also protects against unexpected disruptions with quick and accurate protection measures (Murty and Kumar, 2020) . Under the following factors, load classification is essential for defining the projected operational strategy in a mini grid/micro grid arrangement: (i) The load-source management strategy necessary to meet net active and reactive power requirements in grid-tied mode, as well as voltage and frequency stabilization in island mode (ii) Better power quality (iii) Lower maximum load to improve distributed energy resources ratings, and (iv) maintain desired performance and control (Murty and Kumar, 2020).

2.1.11 Power Balance and Management in Micro Grid System

In order to achieve the best system dependability and operation efficiency, appropriate operation of hybrid energy supply systems with various (Alternative or renewable energy) sources, conventional distributed generations and energy storage (functioning as micro grids) is necessary. A control (or energy management) system must typically determine and allocate active and reactive output power of each energy source while maintaining the appropriate output voltage and frequency. In general, there are three types of control structures for such systems: centralised, distributed, and hybrid control paradigms. Each energy source is considered to have its own (specific) regulator in all three instances, capable of determining the optimal functioning of the relevant unit based on actual data (Murty and Kumar, 2020). The MGEM challenge entails demand side and supply management, unit commitment (UC), and system limits in order to provide an affordable, sustainable, and dependable micro grid operation. From support to frequency stabilization, generating dispatch to energy savings, dependability to loss cost reduction, energy balancing to decreased emissions of greenhouse gases, and customer engagement to customer privacy (Murty and Kumar, 2020). The overall goal is to reduce total micro grid operating costs, but other significant goals like as reducing gaseous emissions and line losses can also be considered.

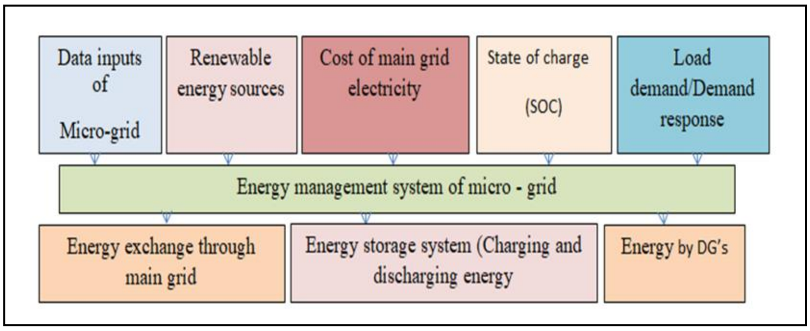


Figure 2.6. Typical micro grid (Grid connected) energy management system

Figure 2.6 indicates typical micro grid energy management system (Murty and Kumar, 2020). Some information, such as DG parameters, ESS availability, predicted load demand, RES generation, and market electricity price for all hours of the day ahead, should usually be known in advance in such a system. These data are fed into the MCG energy management optimization algorithm as input parameters, and the results reveal the ideal generation schedule for the entire day ahead (Murty and Kumar, 2020).

2.1.12 Power Electronics Devices in the Micro-Grid System

There several components constituting the hybrid renewable energy systems depending on the type of renewable energy source, bus bar connection (AC or DC), loads. Power electronics interface modules provide a variety of tasks, including power conditioning (PQ), power conversion, output interface and filter protection, distributed energy resources, ancillary services, load control, controlling and monitoring. Power devices are used to alter the characteristics of electrical power (current and voltage magnitude, phase, and/or frequency) to suit a specific application. Bi-directional converter is one of the significant devices having a great role of interfacing the AC and DC buses (control stability) (Liu *et al*., 2014). The hybrid ac/dc micro-grid has been a great target in the field of electricity generation (Saponaramet *et al*., 2019). In order to reduce the procedures of repeated inverted conversions in an independent ac or dc grid and to simplify the connectivity of different renewable energy sources (ac and dc) and loads to power systems (Liu *et al.*, 2014). In a hybrid ac/dc micro-grid, bi-directional power converters are linked between the ac and dc sub grids, and their dependability and operating efficiency have a direct impact on the hybrid ac/dc micro grid's reliability and economic efficiency. There are two functions of the bidirectional DC/AC converter (Liu *et al.* 2014). The first task is to convert AC to DC, which it accomplishes by acting as a bridge rectifier. The second task is to convert DC to AC, which is accomplished by the use of an inverter.

2.1.13 Switching and Control of Micro Grid System

Because energy and power values are substantially lower in AC micro grids, the examination of stability issues follows the same principles as in grid system. Reactive and real power controls are necessary to adjust both voltage and frequency. Stability is managed by the speed and torque control of the machine shaft when sources such as ordinary generators with an AC power output are connected directly without power electronic connections (Justo *et al.*, 2013). There are no reactive power exchanges in DC micro grid systems, implying that there will be no stability concerns. In a DC-based micro-grid, system control appears to be geared solely at frequency management. A micro grid's stability can be classed into one of two categories. Frequency stability, which includes tiny signal and dynamic stability, is the first, while voltage stability is the second (Elsayed *et al.*, 2015).

There are numerous control techniques (strategies) that help manage the component level of a distribution system, which are listed as follows: (i) Slave and master control, the slaves control the current sources while the master controls the voltage and frequency (ii) Control of current and power flow, this method employs control signals to regulate current and power distribution (iii) Droop control, because the converters act as non-ideal, this strategy is better for combining with prior methods (Bayindir *et al.*, 2014).

A centralized control system obtains intelligence from a single central point, which may be a controller or a server, a switch, or, depending on the network type. A centrally controlled network is simple to operate since it gives the operator more control over the entire system. This capability enables the manager to build wide control techniques to satisfy power demands. The centralised control system, on the other hand, necessitates a single control unit that processes all measurable data. This one-of-a-kind controller point might produce a slew of communication issues, as well as a slew of defects that could bring the entire system to a halt (Bayindir *et al.*, 2014).

In contrast to a "master" controller, the decentralised controller permits a system in which all devices can operate themselves autonomously. For example, a decentralized controller might demand activation or not from a distribution point, increasing the overall system's communication speed. Completely decentralised systems, on the other hand, consolidate a number of issues. Because all choices are made at the distribution level, the manager's ability to regulate the micro grid may be compromised. Such a flaw necessitates the creation of a well-organized control mechanism. The costs of installation decentralized are higher than those of centralised systems. Micro grid communication used approaches (Strategies): One of the most critical features of a micro grid is the communication necessary to undertake control and protection tasks. Wireless communication methods have been deployed in micro grid communication systems used in test beds so far. The criteria should be met by micro grid communications systems are such as (i) Data interchange between all elements of the multi micro grid and inside the micro grid (ii) Data collection and monitoring from all elements (iii) Decentralized control, for example hierarchical control, must be met (iv) Load shedding and real-time generation control, for instance, power management (v) Frequency and voltage control coordination (vi) For total energy management, protection, and control, protocols must be used (vii) Determine whether micro grids are capable of providing quick secondary services (Coelho *et al*., 2017; Bayindir *et al*., 2014) .

2.1.14 Artificial Intelligent Optimization Techniques

A well designed simulation program permits to determine the optimum size of battery bank, PV array, Wind turbine, Hydro generation capacity and other generation system for an autonomous or grid integrated HRESS for a given load and a desired LPSP based on various criteria. Some of the criteria are minimum cost of the system, minimum capacity of system and storage devices, maximum power generation, and minimum LPSP and minimum LOLP. Various optimization techniques such as graphical construction, probabilistic approach, iterative technique, artificial intelligence (AI), dynamic programming, linear programming and multi-objective have been used by researchers to optimize energy systems (Alaaeddin *et al.*, 2019). Figure 2.7 indicates contemporary optimization methods sizing off-grid system.

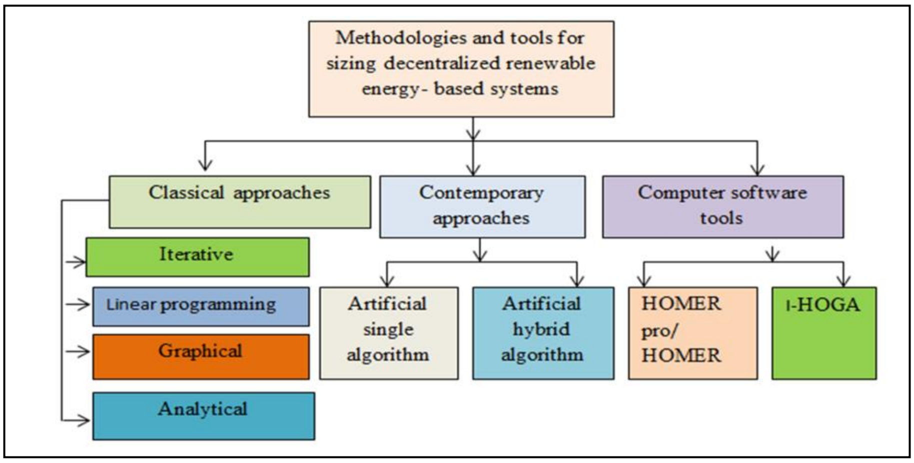


Figure 2.7. Contemporary optimization methods sizing off-grid system

2.1.15 Electricity Market and Concept of Net-Metering

As it has been explained in the previous sections, the global demand for electricity is rapidly rising, while any use of fossil fuels is increasingly constrained by power generation policies and the required compulsion to mitigate the effects of climate change. Therefore, in order to meet the world's demand for electricity, alternative sources of energy are needed particularly solar and wind power. For instance, when oriented solar PV previously came available as a reaction to expanding the portion of power generation from RES, the speculation costs were high in light of the fact that the innovation was genuinely new. The principle objective was to infiltrate a high portion of RES in the power creation blend. In order to do as such, the FiT model was implemented. The primary thought of the FiT model is to ensure the financial support or a motivation for energy production (for a specific measure of time). As innovation improves and establishment costs lessen, fiT funding or motivations (incentives) diminish separately with time (Budin *et al.*, 2021).

The gross metering and net-metering are two approaches for quantifying and measuring the electricity supplied to the grid. All energy production is directly fed to the grid and subject to FiT in the gross measuring method whereas prosumer consumption is subject to current retail rates (Budin *et al.*, 2021).

While the FiT gross metering model requires two meters to be introduced (each toward its of the progression of power), the net-metering model requires just a single meter which turns in a single course while the energy is being drawn from the framework (when the utilization is higher than the PV creation) and twists the other way when the energy is being shipped off the matrix (when the utilization is lower than the PV creation) (Bhuyan, 2017). Rather than the gross metering estimation technique in the FiT model, the net metering estimation strategy utilizes the creation of PV basically for family utilization and is liable to retail duties, while the overabundance of delivered electrical energy is being shipped off the matrix and is likely to net-metering, acquired from. As a piece of the net-metering model, there are two kinds of cost computations: the net metering technique and the net charging strategy (Budin *et al.*, 2021). As per, contingent upon the matrix strategy, the financial backer will either get compensated for the infused abundance power or the credits will be put something aside for the following charging period. In the net metering strategy, the financial backer follows through on the retail cost for the net-metered used power, while the excess power creation is getting banked (or briefly put away) for the forthcoming months and that abundance isn't being offered to the lattice (Budin *et al.*, 2021; Bhuyan 2017). In the net charging technique, surplus power creation is being offered to the matrix at a specific rate (i.e., discount cost of power), while the financial backer follows through on the retail cost for the net-metered used power (Budin *et al.*, 2021). Moreover, the financial backer could actually coordinate his battery stockpiling framework, putting away the abundance power to his private stockpiling framework (not send it to the network at that specific second), and selling it some other time when the circumstances are better, contingent upon the system and calculation of decision.

2.1.16 Energy Generation and Management

Because of fluctuating power output and demand, as well as the inclusion of non-dispatch able generators such as solar and wind, power management of a micro-grid becomes more complex than energy management of traditional power systems. Different techniques, such *direct load controls*, *time-of-use* (TOU), and real-time pricing, have been used to efficiently and effectively manage a network's power (Hossain *et al*., 2021). *Real-time pricing* (RTP) is one of them, and it helps to control a network's power effectively and efficiently because it is dependent on the network's present state (Hossain *et al*., 2021). Because the pricing plan is announced an hour in advance, it is simple to control network power without worrying about prediction mistakes in power generation and demand. Installing energy storage solutions, such as a battery, with variable charging and discharging properties to efficiently operate the micro grid is another option to handle intermittent power generation (Hossain et al., 2021). When there is surplus power generation or low RTP, batteries can store energy and release it when there is low power generation or high RTP (Hossain *et al*., 2021). To control the energy of a micro grid, three categories of power management systems are used, including the *baseline*, *real-time* and *scheduling* energy management systems (Hossain *et al*., 2021). The baseline technique manages energy using a set of rules for each time interval, real-time energy management uses data collected in real time to correct for the influence of uncertainty on network energy management, whereas optimization algorithms are employed in the scheduling technique to tackle an optimization problem for a predefined time frame, such as a day ahead schedule, where expected data is used to discover optimal solutions (Hossain *et al*., 2021). The scheduling program's solutions may not operate successfully as prediction errors rise with increasing uncertainty levels. (a)Without consideration of uncertainties: "*Baseline management approach*", is implemented according to a number of rules (Hossain *et al.*, 2021). It gives simple actions with no guarantee of the lowest operating cost to regulate the micro grid's battery energy. As a result, putting this core strategy into practise is simple; "*Real-time management approach*", is carried out using an optimization technique, the data collected is used to determine the best solutions (optimization) to the energy management problem, and "*Scheduling management approach*", In this kind of management, correctness of forecasting is the most important aspect of a scheduling software since it is entirely dependent on the expected data and plans subsequent activities in the network based on it (Hossain *et al.*, 2021). If the projected data changes, solutions may not work as well as they should. (b) With consideration of uncertainties: Uncertainty on the scheduling program through the introduction of several electricity prices on the predicted data, the cost other scheduling program for the micro grid is calculated as it is performed using the predicted data and it has no relationship with the current data or error in forecasting and measuring data (Hossain *et al.*, 2021). In contrast, the real-time and baseline approaches are evaluated based on the sample data of electricity prices due to the fact that they work in current data and therefore are free from uncertainty, and energy management using time of use (TOU), many parts throughout the world employ TOU to relocate load demand from peak to off-peak periods, albeit this strategy may not function as well when there is a high penetration of RESs in power distribution network due to the volatility in their power supply (Hossain *et al.*, 2021)

2.2. SUMMARIZED SYSTEMATIC RELATED LITERATURE REVIEW, RESEARCH GAPS AND FORMULATION OF PROBLEMS

2.2.1 Summarized Systematic Related Literature Review

Literature survey covers various aspects which includes feasibility analysis of renewable energy systems, energy demand estimation, sizing of various renewable energy sources along including storage requirements, power quality issues within and outside of the generating system of renewable energy-based hybrid system. Some accrued insights acquired from detailed systematic related literature survey are summarized as follows:

- Preliminary feasibility analysis is a foremost stage for designing hybrid renewable energy -based system at a given site. Researchers have used different ways on how to determine optimal configuration of hybrid renewable energy system (Yaşlı and Soujeri, 2010; Vyas, *et al*., 2015).
- Feasibility analysis involves the technical-economics of renewable energy generating systems in rural areas. The cost of power generation using these systems differs from place to another starting from site locations of same country to different countries. This also depends on the potential of renewable energy resources in a given place (Bakos and Soursos, 2002).
- In the environment where central grid is available it is common to consider integration with off- grid system. In grid integration mode HRESS is usually supported by main grid

(GHRESS) and sometimes weak main grid is supported by local distributed generation (Li *et al.*, 2022). Normally during planning and designing phase of HRESS on- grid operation (GHRES) is not considered due to remoteness away from the main grid. However, electrification in developing countries is an on-going duty of providing electricity through off grid and central grid systems. Therefore, installations of both off -grid and on-grid systems are still evolving. In this situation off-grid systems will gradually increase in parallel with grid extension reaching the remote area. After long period of time there is a possibility for these systems to be in proximity.

- Modeling of SHRESS with applications is limited to few rural areas. Literature indicates that modeling regarding locations like individual villages and clusters, blocks or district is still limited. The focused development and utilization of energy plan separately at village level is necessary. However, for a long time few studies on modelling about for village electrification have been conducted (Hiremath *et al*., 2007).
- HOMER uses hourly load and environmental data inputs to perform hourly simulations for techno-economic analysis of hybrid energy systems. HOMER is used to carry out simulation, optimization, and sensitivity analysis. In the simulation process, it models the hourly performance of a power generation system configuration for techno-economic analysis of the system (Pujari and Rudramoorthy, 2022).
- HOMER facilitates the optimization and sensitivity analysis of simulated renewable energy systems to minimize the Net Present Cost (NPC) for a given set of constraints.
- Sensitivity analysis is a measure that checks the sensitivity of a model when changing the value of the parameters of the model and also changing the structure of the model.
- As various powers electronic components or devices are deployed for voltage conversions like DC-DC conversion, DC-AC conversion, voltage transformations and so on.at different levels of HRESS. These power electronics components or devices cause power quality problems.
- In recent years, Soft computing techniques have been widely used to optimize a hybrid system in order to maximize its economic benefits.
- In order to gain the balance between energy supply and energy demand of a given area power generating system needs to be optimal. This means the system should be reliable, efficient and economically viable. Sizing the system for optimal condition call for suitable optimization technique.
- The optimization technique can assure the lowest cost of investment, high efficiency and reliability of power generating system (Xu *et al*, 2013). The optimization of hybrid

renewable energy systems undertakes the selection and quantification of the best system components, proper size and energy management strategy for availability, affordability and reliability of decentralized renewable energy system.

- Artificial intelligent (AI) optimization approaches gives better optimization solution than a conventional optimization method. Artificial intelligence is a term that in its broadest sense would mean the ability of a machine or artificial to perform similar kinds of functions that characterize human thought. In other words, meta-heuristic search techniques have been extensively used for optimizing complex systems (Ibrahim *et al.*, 2022).
- GWO outperforms other competing methods in battery sizing and energy management in micro grids (Nimma et al., 2018).
- Solar house systems (SHS's) are the best option for rural areas which are normally characterized by remote dispersed households, low demand, less (Scattered) population density, and logistic challenges hindering the grid extension. However, SHS's are capable of expanding access to electricity in such locations but are incapable of generating sufficient power for economic activities services (Azimoh *et al.*, 2016) .
- Mini grid or micro grid systems particularly hybrid renewable energy based micro grid systems are the best option not only for increasing access to electricity but also for providing enough power to rural areas for economic activities services. They are also environmentally sustainable. However, any hybrid energy system involves an integration of dissimilar energy resources which is complex and their intermittency is also a challenge. They need comprehensive analysis for their improved performance *(*Rezaei *et al.*, 2021).

2.2.2 Research Gaps

Based on the surveyed literature, research gaps were identified as follows:

- Different places have difference potential/weather statistics and prices of renewable energy sources. Generating power from renewable energy sources need feasibility study.
- There are many commercial and non-commercial configurations of HRESS models for rural electrification with a limited micro hydro-based power systems and village electrification models'
- There are many studies about design and development of decentralized HRESS in rural areas without appropriate optimization techniques as renewable sources intermittent.

Sizing and modeling of hybrid renewable energy system for village electrification the system need artificial intelligent techniques.

- Use of electronic equipment in the design and development of HRESS causes power quality problems like voltage instability and harmonics. Any design of GHRES S calls for power reliability system analysis.

2.2.3 Formulation of Problem

Low level of rural electrification, reduced capacity as a result of frequents droughts, financial limitations of grid extension and emerging economy especially in developing countries tends to increase energy demand. In addition, excessive reliance on fossil fuels for power generation has led to energy scarcity and global warming. Diesel generators are popular for generating power supply in both off-grid and on grid system applications. Fossil fuels are immensely depleting with unpredictable rising cost thus threatening energy security. An option of producing power by diesel generators is neither economically viable nor environmentally friendly. Unfortunately, high potential of renewable energy resources in the country is underutilized. This high potential of renewable energy resources can be fully tapped to meet energy demand through renewable energy- based micro grid system. Renewable energy based micro grid reduces the dependence on main grid power supply, improves power quality and minimizes the cost of energy storage system. Due to variance of renewable energy sources hybrid of distribution generations are integrated to micro grid. These hybrid systems are promising choice for meeting energy requirements in educational institutions, hospitals, industries, telecommunication towers and remote rural communities. The design of any hybrid renewable based system should sound both technically and economically. However, designing process for cost-effectiveness and reliability of hybrid renewable energy system is difficult as it involves different energy sources with different characteristics. In addition, few studies have presented about integration of renewable energy sources in autonomous remote rural micro grid. Based on the literature survey and after going into the detail of proposed area, the problem has been formulated for study and implementation in the thesis. The aim of the proposed research work is to perform techno-economic analysis of renewable energy based micro grid systems for rural applications

2.3 CONCLUSION

Energy plays a great and important role in our daily life for socio-economic development. Economic development of a particular country is direct proportional to the level of energy consumption. Developed countries normally have higher level of energy consumption than less developed ones. Developing countries especially in the SSA region face the problem of energy poverty. Also, the approach of addressing energy shortage via conventional energy sources is not appreciated because are expensive, insecure, depletive, and pollutant.

Non-conventional energy sources (Renewable) can be adopted to address the problem of energy deficiency and negative impacts to environment. Renewable energy sources are beneficial as are replenished, sustainable; secure (Ensure energy security), and are ecologically friendly. Similarly, grid extension is expensive to transmit and distribute power to district power to distant off-grid locations. In most cases power grids in developing countries are unreliable with tendency of frequent outages and shedding. Therefore, decentralized renewable energy-based systems can be used to increase access to modern energy services including electricity particularly in off-grid locations of developing countries. In addition, deployment of local decentralized renewable energy based systems is useful for joining the global efforts of mitigating the harmful emissions from fossilized energy systems. Renewable energy resources particularly solar and wind energy sources are sporadic in nature. Knowing the technical and economic parameters is important for reliable and good economic performance of the system.

Therefore, the techno-economic feasibility analysis of the system is carried out prior to an implementation of renewable energy-based system expected to supply power to a particular off- grid area. Artificial intelligent optimization techniques have proven useful for the analysis of off-grid systems.

CHAPTER 3

TECHNO - ECONOMIC FEASIBILITY ANALYSIS OF STANDALONE SOLAR PV (SPV) SYSTEM

3.0 GENERAL

Recently, there has been a greater emphasis on the use of renewable energies and distributed generation power sources to reduce the irreparable impairment inflicted by the use of fossil fuels, as well as a trend toward lowering electricity production expenses, improving access to electricity enhancing power quality, reliability, and lowering losses. The trend of nowadays, centralized fossil fuelled electric power generating systems especially the widely used decentralized DG systems are either completely being replaced (substituted) or hybridized with renewable energy-based system for getting sustainable, cost-effective and environmentally friendly systems (Rezaei *et al*., 2021).

Solar PV module is a type of distributed generation source that may collect solar energy and produce electricity. One of the applications of solar PV systems is provide electricity to domestic household, that is, solar house systems (SHS) (Azimoh *et al*., 2016). Because solar PV panels are not installed indoors, there are several environmental elements such as wind velocity, dust, moisture, bird excreta, precipitation, solar radiation, and air temperature can all have an impact on the performance of PV systems (Gupta *et al*., 2019). However, temperature is a major cause that can impact the performance of solar panels.

3.1 MODELLING AND OPTIMIZATION OF SPV SYSTEM

The mathematical model of the parts of the system determines the appropriate proportions of any renewable energy-based system. Solar PV system was mathematically modelled in this study. Solar PV system requirement is to achieve maximum power due to its non-linear power characteristics.

3. 1. 1 Sizing and Design of Renewable Energy Source Based System

This specific section intends to define the terms in relation with the design and optimization of the renewable energy system. Following are the definitions of the terminologies with respect to the system design and optimization:

I. Mathematical modelling of the system refers to the representation of physical system or sub-system using numerical approach.
II. Objective function refers to an expression of minimising (maximising) optimization problem under specified constraints.
III. Constraints are equality and inequality restrictions imposed on possible solutions.

3. 1.2 Mathematical Modelling of Solar Energy Source

Model of power generation of solar energy source: Solar radiation, which is a free fuel for the solar power generation system is inter-connected in series and parallel to form PN type semiconductor PV panels, which are designed to generate energy primarily by the photoelectric effect. Since N_{PEL} in parallel and N_{SER} in series in equation (3.1) for connected panels may be affected by array voltage in the current (Siddikov *et al.*, 2022).

$$I = N_{PEL}[I_{PH} - I_{RVS} \text{ [EXP } (\frac{q\ (V + R_{SER}}{FKTN_{SER}})]] \qquad (3.1)$$

Considering I_{RS} in equation (3.2)

$$I_{RS} = (I_{RR}(\frac{T}{T_R}) \text{ ^3 } EXP\ [\frac{E_G}{FK}\ (\frac{1}{T_R} - \frac{1}{T}) \qquad (3.2)$$

Where q is the electron charge (1.6 × 10^{-9} C), K refers to the constant of Boltzmann, F is the diode's theoretical factor, and T is the panel temperature (K). The I_{RS} designates the inverse saturation current in the panel, T_R stands for temperature of the panel, I_{RR} defines the reverse saturation current, and E_G represents the band gap energy of the semiconductor utilized in the solar panel.

Solar cells are commonly represented by a single diode, as shown in Figure 3.1 and an electronic system containing a diode, as shown in Figure 3.2

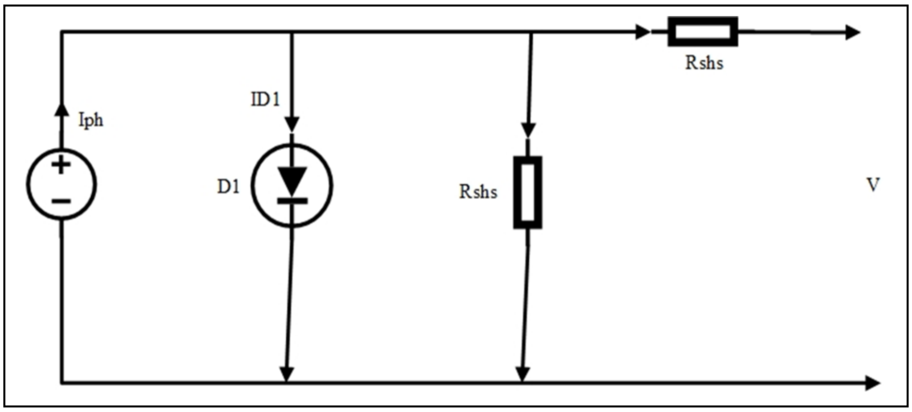


Figure 3.1. Single diode model of solar PV panel

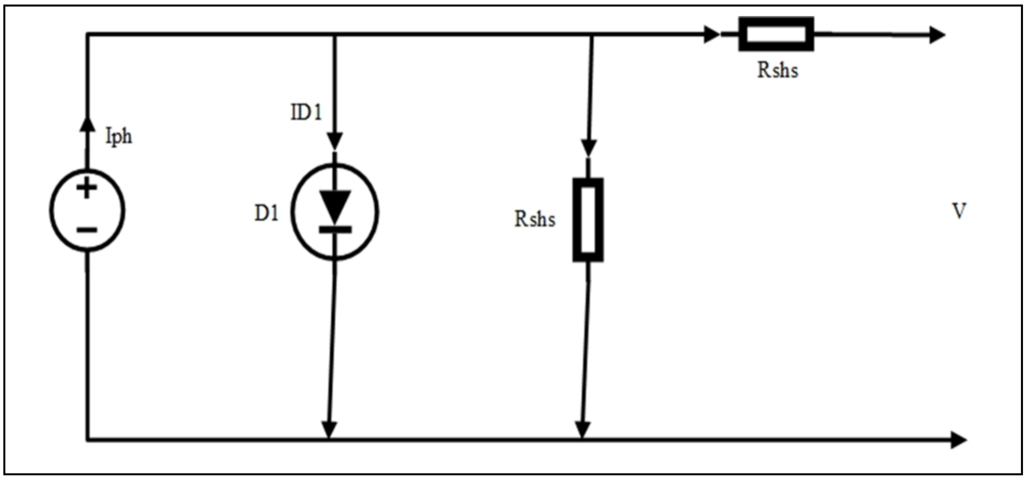


Figure 3.2. Double diode model of solar PV panel

Being in parallel with an ideal shunt diode model, the single-diode model employs an additional shunt resistor. The PV panel's I-V characteristics can be calculated using a single-diode model, as shown below:

3.1.3. ESTIMATION OF POWER FROM SOLAR PV SYSTEM

The amount of power generated by a solar panel depends on the amount of sunshine and the temperature of the surrounding environment (Siddikov *et al.*, 2022). This model computes the power output as follows in equation (3.3).

$$P_{PV} = G_t * A_{PVP} * ή_{PVE} \tag{3.3}$$

Where $ή_{PVE}$the PV is output efficiency, A_{PVP} stands for the PV generator size (m2), and G_t is the solar radiation modulus plane (W/m2). The term $ή_{PVE}$ is computed as follows in equation (3.4) [Source: (Siddikov *et al.*, 2022):

$$ή_{PVE} = ή_{PC} * ή_r[\, 1 - \beta(T_C - T_{C_{Ref}} \tag{3.4}$$

Where,

$ή_r$ = Reference module efficiency

$ή_{PC}$ = Power conditioning efficiency (Equals to 1 with application of MPPT)

β = Temperature coefficient (Ranges from 0.004 to 0.006 / º C)

$T_{C_{Ref}}$ = Reference temperature

The reference temperature $T_{C_{Ref}}$ can be expressed by the following equation (3.5) (Siddikov *et al.*, 2022):

$$T_C = T_a + (\frac{NOCT-20}{800})\, G_t \qquad (3.5)$$

Where,

T_a = Ambient temperature (° C)

$NOCT$ = Nominal operating cell temperature (° C)

The total solar radiation in a solar cell can be approximated as follows due to the simplicity and diffusion (Siddikov *et al.*, 2022).

$$I_T = (I_b * R_d) + (I_d * R_d) + R_r(I_b + R_b) \qquad (3.6)$$

Temperature, insulation, mass voltage, and insulation, of a solar cell all influence its performance [(Siddikov *et al.*, 2022)]. Thus, in order to move the voltage level closer to the highest power point in a varying atmosphere, a highest power search system must be implemented. Finding the greatest solar power is significant because it lowers the cost of operating the solar

3.1. 4 Global and Local (Tanzania) Potential of Solar Energy

Globally, the application of solar energy is progressively increasing so as to address the energy shortage in rural areas of developing countries.

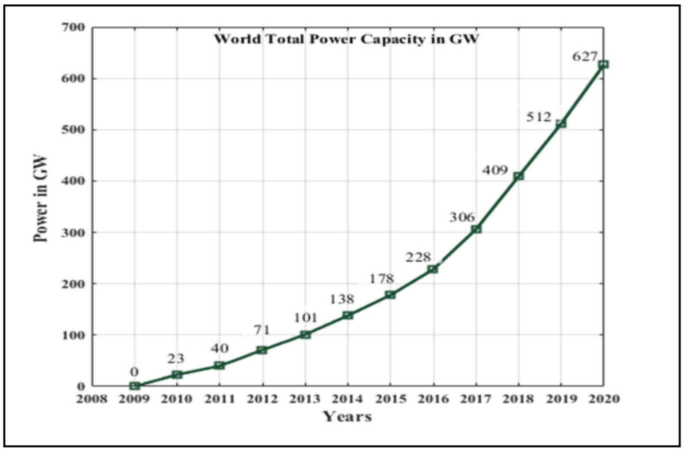


Figure 3.3. Global solar PV capacity and yearly increments, 2009-2020 (Mwakitalima, et al., 2021)

Off-grid solar PV system is widely used to supply power to these rural areas which mostly are characterized by low and scattered population where grid extension becomes technically and economically impractical (Mwakitalima *et al.*, 2021). Figure 3.3 depicts the development of the utilization of solar energy for rural electrification.

Tanzania is located near the equator at latitudes 1-12 S and longitude 20-41 E. In this sense, the country has high solar energy intensities, ranging starting from 2800 - 3500 hours of sunlight per year, with global radiation ranging from 4 - 7 kWh/m2/day. Solar radiation is often high in the country's central areas (Mwakitalima et al., 2021). The available quantity of solar can be fully used to address the high energy demand in the village. Figure 3.4 indicates map of Tanzania illustrating the potential for solar energy.

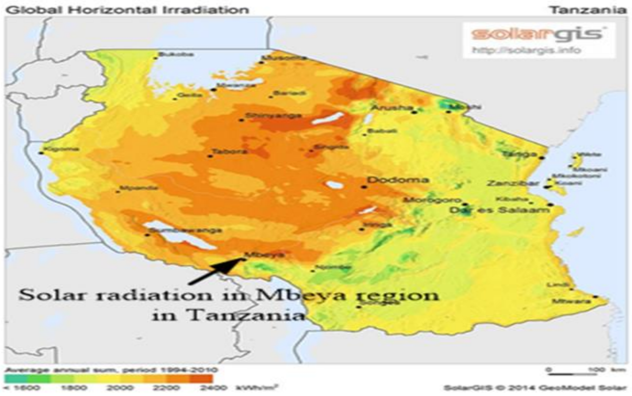


Figure 3.4. Map of Tanzania illustrating the potential for solar energy (Mwakitalima *et al.*, 2021)

Solar photovoltaic technology is being utilized for water pumps, lighting, water refrigeration, and telecommunication towers. Energy from the sun is used at a higher rate in rural areas, where it accounts for around 65 percent of total energy consumption, compared to cities and towns, where it accounts for approximately 3.4 percent. Off-grid solar lighting or tiny solar products (1-10W), solar housing systems (SHS), and small grid solar (PV) systems are examples of solar PV applications (Mwakitalima *et al*., 2021).

The main purpose of this article is to investigate the technical and non-technical elements of utilizing the solar energy potential using an autonomous SPV system, specifically for providing electricity to rural households (SHS) located at the chosen site of Simboya village in Tanzania. There are four steps that must be taken in order to achieve the primary goal of this study. Specific aims include: The first goal is to research the prospects and challenges associated with the whole adoption of solar Photovoltaic system for generating electricity in Tanzania. This goal is reinforced with proposals for improved access to power. The second goal of this paper is to investigate the potential of solar energy by installing standalone SPV supply of electricity to rural homes. This essay also looks into the financial viability of an independent SPV supply system in rural areas for a specific household. Using HOMER, an independent SPV system and an alternate DG set are evaluated by means of environmental and economic benefits. Fourth, the study is broadened by minimizing NPC using the particle swarm optimization (PSO) approach, which is implemented in MATLAB (Mwakitalima *et al*., 2021). The results of the HOMER programme and the PSO are then compared.

This study adds to the identification of potential and shortcomings in successfully utilizing sunlight for generating electricity via off-grid SPV systems, and from the suggestions provided, better rural electrification planning can be realized. Second, the findings of a thorough technical, economic, and ecological plausibility analysis can persuade investors, developers, and other power stakeholders to encourage and deeply engage in rural electrification via standalone SPV systems for residential applications (Mwakitalima *et al.*, 2021). Third, the study is useful for policy formulation and raising awareness among rural families about the benefits of SHS against DG systems. DG systems are mostly used for powering households in rural areas of developing countries (Mwakitalima et al., 2021).

3.2 AREA OF STUDY AND METHODOLOGY

This section of describes the selected area of study and methodology of this particular study. Description of the area of study and methodology is as follows:

3.2.1 Area of Study

The feasibility study focuses on tiny domestic households in the community. Table 3.1 depicts the planned site's profile and main focus.

Table 3. 1: The site's profile (Mwakitalima *et al*., 2021).

Particulars	Explanation
Concentration of study	Small rural domestic household
Name of the village at which the rural home is located	Simboya village
The village's establishment	1998
Quantity of sub-villages '*Vitongoji*'	09
Number of households	483
Electricity availability (Access)	O
Ward title	Ikukwa
District	Mbeya Rural
Region	Mbeya
Locality	Latitude 8° 42.6´ S, Longitude 33°27.9´E
Country	Tanzania

Source: Survey by authors (August, 2019)

3.2.2 Methodology

This paper has two distinct purposes. The first goal is to assess the current application level of solar PV distributed power generation systems for Tanzanian rural electrification. The second goal is to build a solar PV/battery storage system to meet the energy demand of a modest domestic dwelling placed in designated off-grid locations in the nation for validation purposes. The best solar PV/battery energy design is matched to DG of similar capacity. SWOT analysis is used to analyze the actual situation of solar PV implementation used for power distributed supply comprising rural electrification in Tanzania using well-established indicators/criteria derived from review of the literature and field observation *(*Mwakitalima *et al.*, 2021). Simulation of feasibility study of Solar PV distributed system is implemented in HOMER software. When carrying out feasibility study, availability of renewable energy sources, potential of sources and electrical load demand of proposed system are evaluated. Based on the lowest net present cost (NPC) with its corresponding cost of energy (COE), optimal design is chosen. Similarly, PSO technique is also used to minimize NPC's of the proposed technologies and its results are compared with that of HOMER software (Mwakitalima *et al.*, 2021). Total NPC and COE are defined and calculated as follows: Total NPC refers current value of all returns earned over project lifetime. Total NPC is computed using equation (3.7).

$$NPC = \frac{C_{ann.tot}}{CRF_{i,N}} \tag{3.7}$$

where, $C_{ann.\ tot}$ is an overall annual price (\$/year), i is an interest rate in percentage, N is a number of years for a project lifetime and CRF represents capital recovery factor. CRF is computed using equation (3.8)

$$CRF = \frac{i*(1+i)^N}{i*(1+i)^N - 1} \tag{3.8}$$

COE refers to average price of electricity per kWh and is computed as follows using equation (3.9)

$$COE = \frac{C_{ann.tot}}{E_{Primary,AC} + E_{Primary,DC} + E_{Grid,sales}} \tag{3.9}$$

Where, $E_{Primary,\ AC}$ is an AC primary load served (kWh/year) ; $E_{Primary,\ DC}$ is a DC primary load served (kWh/year) and $E_{Grid,\ sales}$ are grid power sales (kWh/year).However, in this specific study DC primary load and grid power sales are negligible. Therefore, COE is computed as using equation (3.1)

$$COE = \frac{C_{ann.tot}}{E_{Primary,AC}} \tag{3.10}$$

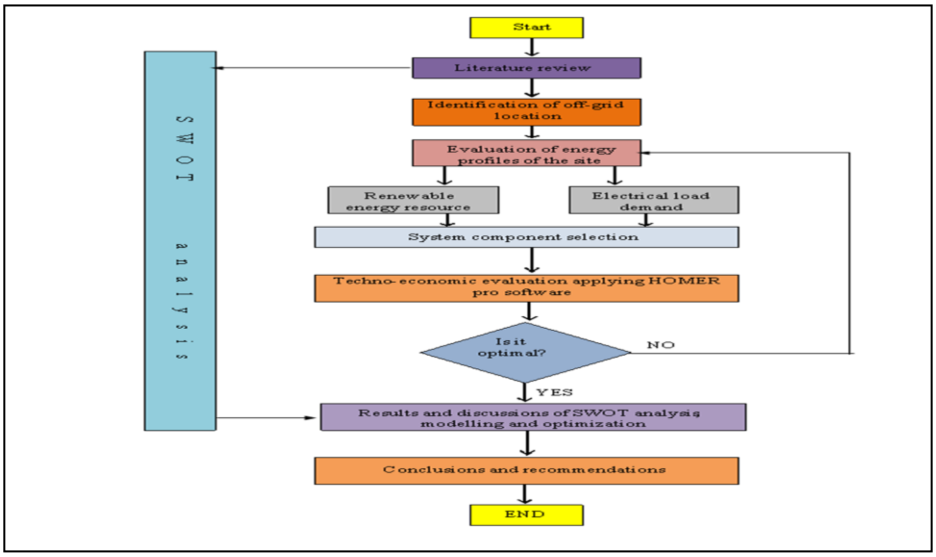


Figure 3.5. Research conceptual framework (Mwakitalima et al., 2021).

The study framework is depicted in Figure 3.5. Table 3.2 indicates the situational (SWOT) analysis for solar PV development and implementation in Tanzania for power generation.

3.2.2.1 Solar power resource

The National Aeronautics and Space Administration (NASA) and Surface Meteorology and Solar Energy provide monthly solar radiation statistics (SSE) (NASA, 2019). The annual average solar radiation in the research area is 6.11 kWh/m2/day. This intensity of solar energy is sufficient to generate power at the suggested location. Figure 3.6 illustrates the suggested region of study's clearness index and solar irradiance (Mwakitalima *et al.*, 2021).

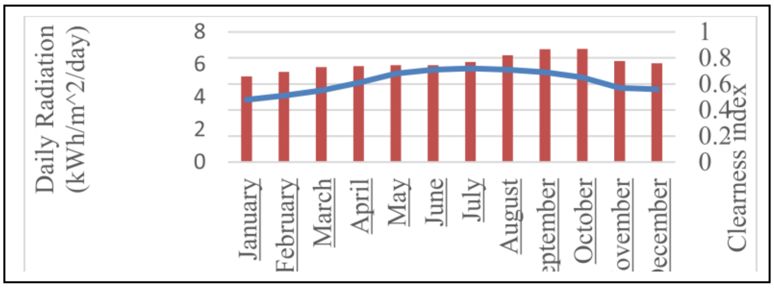


Figure 3.6. Clearness index and solar irradiance (Mwakitalima *et al.*, 2021).

Table 3. 2: Situational (SWOT) analysis for solar PV development and implementation in Tanzania for power generation (Mwakitalima *et al.*, 2021).

TF	Findings/Description of analysis
S	▪ Government of Tanzania supports renewable energy technologies to address energy deficit in rural areas ▪ There is a sufficient coverage of solar energy resource almost all over the country and therefore rural energy problem can be addressed through solar PV technology ▪ Good environment of private sector participation in investment of renewable energy based projects ▪ The country is politically stable for investment in large solar PV projects. ▪ Continued good relation with development partners in power related matters ▪ High commitment by GOT which highly supports investment in power related projects ▪ Tanzania has joined global effort to protect environment through utilization of renewable energy technologies including solar PV technology [1] [53] [54] [55] [56] [57] [58] [59]
W	▪ Few areas has low potential of solar energy resource ▪ Solar PV technology uses solar resource which is intermittent in nature demanding for energy storage systems ▪ Solar PV technology has high initial cost and leveled cost of energy ▪ No large scale centralized solar PV systems ▪ Limited feed –in-tariff for solar PV technology (first time in Kigoma region) ▪ Absence of net –metering policy ▪ Solar PV integration issues ▪ Long payback period ▪ Low efficiency of solar PV technology ▪ Limited capacity for solar PV projects for reduction of GHE emission under CDM scheme ▪ Lack of awareness ▪ Lack of financing mechanisms / schemes ▪ Insufficient skilled personnel with solar PV technology ▪ Low level of research and developments regarding solar PV technology ▪ Dependence on imported technology [53] [60] [61]
O	▪ Availability of high demand of electricity in rural areas of Tanzania ▪ High potential of solar energy resources is suitable for off-grid power supplies. ▪ Demand of water supply in off grid areas may be achieved through water pumping system using Solar PV power ▪ Availability of development partners to support energy sector ▪ International recognition of solar PV technology for addressing environmental concerns ▪ Cost decline of solar PV technology (Kusekwa 2011, Ishengoma 2013, Bertheau, Cader et al. 2014, Mgonja and Saidi 2017) [1] [**11**] [53] [62] [63]
T	▪ Environmental pollution without proper disposal of equipment like battery etc. ▪ Theft of solar PV panels ▪ Possibility of imported substandard solar PV equipment ▪ Uncertainty of material supply for solar PV technology may affect the influx solar modules of local level ▪ Unsustainability of the systems if donations from development partners are cut down [1] [53] [62] [63]

Note: TF= Type of feature; **S**= Strengths; **W**=Weakness; **O**= Opportunities; **T**= Threats

3.2.2.2 Estimated Rural Household Electrical Load

The energy requirement for the typical rural household has been calculated based on the equipment often used in remote parts of the country. The load demand was calculated using fluorescent and energy-saving lighting, as well as entertainment and other devices such as a DVD player, TV and radio sets, a mobile phone charger, and an electric iron. Many villages in rural areas do not utilize heaters, electric fans, refrigerators or air conditioners, or refrigerators for heating and cooling (Mwakitalima *et al.*, 2021).

Table 3.3: Energy use of a typical household in Simboya Village, Tanzania (Mwakitalima *et al.*, 2021)

Appliance/ Equipment	Number	Power (W)	Time (h)	Total Power (W)	Energy (Wh)
Fluorescent lighting	1	20	7	20	140
saver lamp (indoor)	3	2	5	6	30
Saver lamp (outdoor)	2	2	12	4	48
TV set	1	65	6	65	390
Radio set	1	20	2	20	40
DVD player	1	15	5	15	75
Mobile Phone charger	3	7	2	21	42
Electric iron	1	1000	0.5	1000	500
Refrigerator	1	200	12	200	2400
			Total	1351	3665

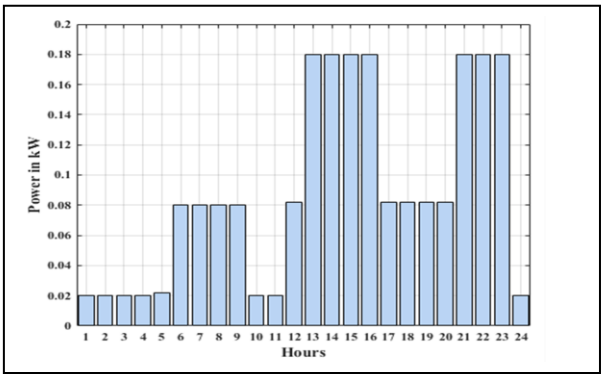


Figure 3.7. Electrical load profile for a potential site (Mwakitalima et al., 2021).

Table 3. 3 and Figure 3.7 show the energy requirement and load pattern for a hypothetical typical rural household in Simboya community, Tanzania.

3.3 RESULTS AND DISCUSSIONS: USING OF HOMER PLATFORM

The proposed solar PV system concept consists of various components such as battery energy equipment, solar PV panels, a converter, and electrical loads. This standalone solar PV device is compared to its similar diesel-powered generator for the same purpose. The estimated daily electrical consumption is 1. 6 kWh. In Table 3, the power required has been calculated using relevant equipment. This work accounts for 20% of the expected electrical load's power losses (Mwakitalima *et al.*, 2021) As seen in Figure 6, a daily load pattern has been developed. Figure 3.8 and 3.9 show the optimized solo solar PV panel with battery bank and its schematic representations of the suggested site in this work. Figure 3.10 shows the corresponding DG when compared to the ideal SPV design.

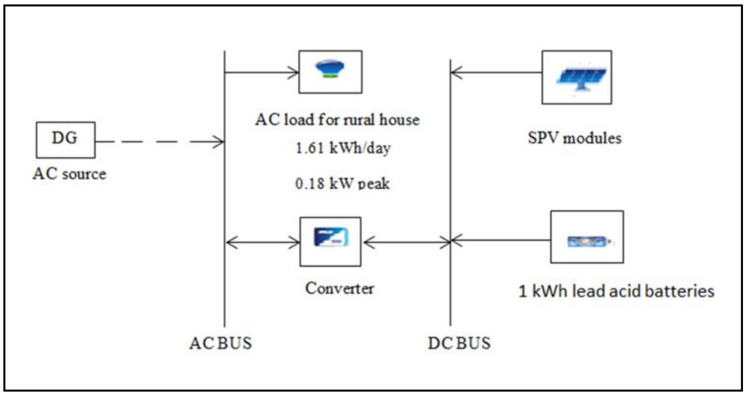


Figure 3.8. Schematic illustration of a solar PV-battery energy storage system (Mwakitalima *et al.*, 2021)

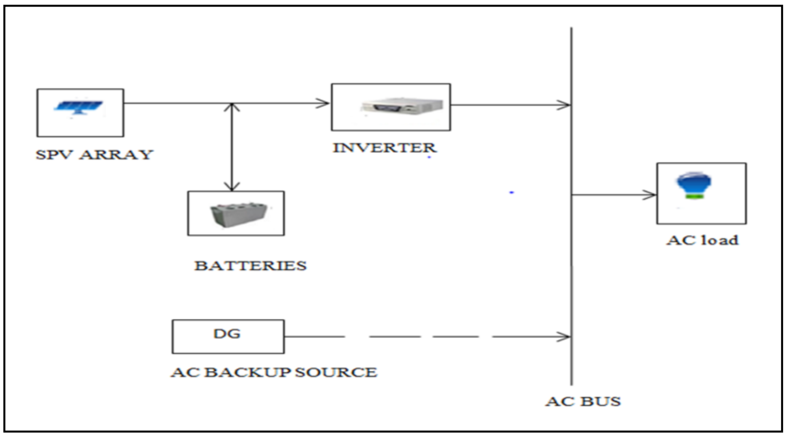


Figure 3.9. Schematic sketch for planned solar PV powering (Mwakitalima *et al.*, 2021)

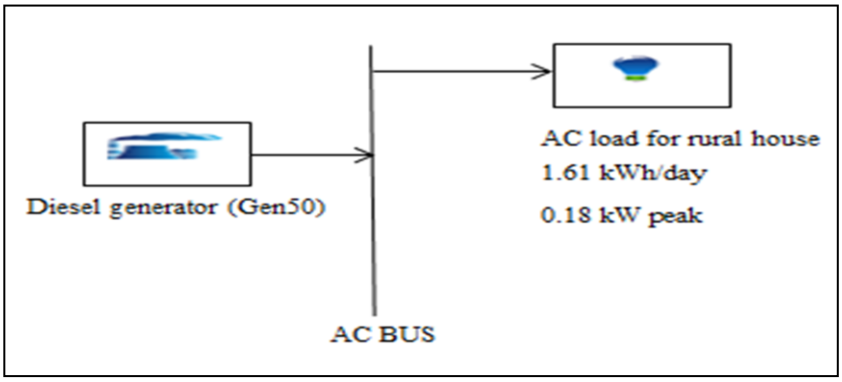


Figure 3.10. DG system schematic sketch (Mwakitalima et al., 2021).

3.3.1 Optimal Solar PV-Battery Storage System Design

The optimal system was considered based on cost-effectiveness. Figure 6 (a) depicts optimization findings, which are stated as follows: Generic plate solar PV with a total installed capacity of 1.8 KW, 4 Generic Lead Acid batteries, each with a capacity of 1 kWh and a nominal voltage of 12V (2 in succession per string with 2 parallel strings creating a system voltage of 24V), and a converter with a capacity of 0.4 KW. This inventory of electrical equipment is sufficient to satisfy the load requirement with a one-and-a-half-day autonomy. The inverter has a capacity of 0.4 kW. This means that if the solar PV production is sufficient to meet the electrical load, the battery energy system will be enough to provide power in the absence of solar radiation. Furthermore, the planned rural site's daily electricity usage and peak power are 0.16kWh/day and 0.18 kW, respectively. In truth, this level of consumption is minimal since rural residences have a low load factor of roughly 0.37 due to restricted electrical appliances, the majority of which are lighting, entertainment, and cooling equipment. Cooking and space heater and/or conditioning equipment are not included because rural inhabitants cook with biomass and the weather is pleasant. According to this viewpoint, the anticipated battery storage system will provide enough power for approximately one and a half days in absence of sun rays. As dusts on top of photovoltaic arrays may be mopped up by the house owner, operating and maintenance costs were omitted during the optimization process. The technical comparison of ideal solar PV-Battery storage against DG is shown in Table 3. 4.

Table 3.4: Technical comparison of solar PV-Battery storage against DG (Mwakitalima, *et al.*, 2021).

Technology	Capacity (kW)/Nos.)	CS	Load (kWh/ day)	Peak power (kW)	REP (%)
Solar PV/ Battery	1.8 kW	LF	1.61	0.18	100
Solar panels	1.8 kW	-	-	-	-
Converter	0.4 kW	-	-	-	-
LA batteries 12 V	4 nos. ,24 V system	-	-	-	-
DG	1.8 kW	LF	1.61	0.18	0

Note: S = Control strategy, LF = Load following, REP = Renewable energy penetration

3.3.2 Economic Analysis of Optimal Solar PV-Battery Storage System Versus DG

The optimization of a diesel generator of the same capacity as a solar PV 1.8 KW and a lifetime of 15, 000 operational hours has been completed. The capital cost of a DG system is lower than that of photovoltaic (PV) technology. However, the operating costs of DG are higher than those of its cousin SPV. Table 3.5 compares the economics of optimum solar PV with battery bank against DG only.

Table 3.5: A cost-benefit analysis of solar PV panel with battery bank against DG only (Mwakitalima *et al.* , 2021).

Parameter	Technology for rural electrification	
Financial parameter	SPV/ Battery storage system	DG
Initial cost ($)	2,422	500
Total NPC ($)	3,013	28,116
COE ($/ kWh)	0.397	3.71
Operating cost ($/ Year)	45.71	2,136
Fuel cost ($/Year)	0	1,597

The diesel generator's fuel consumption and GHG emissions of carbon monoxide, sulfur dioxide, carbon dioxide, particulate matter, nitrogen oxide, and unburned hydrocarbon are presented. It is obvious from Table 4 that the DG system emits significant GHG emissions whereas the SPV emits negligible. If a diesel generator of comparable capacity as an SPV system was placed in a rural residence, it would emit roughly 4,179 Kg of CO2 per year. According to the authors' survey, there are 843 households in Simboya village. If rural electrification in this hamlet is implemented entirely by SPV systems, approximately 2,018,457 Kg of CO2 can be avoided each year. Solar energy is non-polluting, infinite, and costless. GHG emissions from DG are shown in Table 3. 6.

Table 3.6: GHG emissions from a diesel generator-powered system (Diesel generator fuel usage)

Parameters	Fuel consumption and Emissions (DG)	Fuel consumption and emissions (SPV- battery storage system)	Unit
Carbon dioxide	4, 179	0	Kg/year
Carbon monoxide	26.1	0	Kg/year
UHC	1.15	0	Kg/year
Particulate matter	O.156	0	Kg/year
Sulfur dioxide	10.2	0	Kg/year
Nitrogen oxide	24.5	0	Kg/year
Fuel consumption	1, 597	0	Litre
SFC	0.405	0	Litre/kWh
Fuel energy input	15, 710	0	kWh/year
MEE	25.1	0	%

Note: DG= Diesel Generator, UHC= Unburned Hydrocarbons, MEE= Mean Electrical Energy, SPC = Specific Fuel Consumption

3. 4 RESULTS AND DISCUSSIONS: APPLICATION OF PSO APPROACH

HOMER software is used to solve linear equation problems without displaying the real RES parameters. As a result, numerous artificial intelligence techniques can be used to handle nonlinear issues. PSO algorithm is one of these artificial intelligence (AI) optimization techniques. As a result, the PSO approach, in addition to HOMER, was used in the study. Various optimization approaches and procedures are classified as AI techniques. The Particle swarm optimization (PSO) is one of the most important AI algorithms.

The optimization performance is determined by the suitable selection of PSO process input parameters. This algorithm is based on the modelling of collective behavioural representation as a replacement for survival of the fittest. The advantages of this optimization technique include its high efficiency, simplicity, fertility, and ability to initialize a swarm of particles in the exploring space at randomized speeds.

In order to determine the expression with new variables at a particular iteration, the place and speed of an item are altered. A single PSO particle leaves trails in the exploring space for its coordinates that are connected to the best outcome it has achieved to this point, and this best value is known as Pbest. If a particle approaches the overall ideal population (achieved superior value), it is referred to as the global best, Gbest. The velocities of are constantly modified in response to the particle's current velocity, as seen in equation (3.5) below:

A solitary molecule of PSO saves trails for its directions in the investigation space, which are connected with ideal outcome it has accomplished this point and this wellness esteem is called Pbest. Assuming the molecule arrives at the generally ideal populace (accomplished unrivaled worth) is called worldwide best, Gbest (Mwakitalima *et al.* , 2021).

.Velocities are continually changed according to the current velocity of the particle, as given in Equation (3.11) (Mwakitalima *et al.* , 2021):

$$v_i = w(t)v_i + C_1\, r_1\, P_i\,(t) - x_i(t) + C_2\, r_2\, G_i\,(t) - x\,(t) \tag{3.11}$$

where C_1 and C_2 are acceleration constants which are accountable for variation of particle velocity in the direction of Pbest $P_i\,(t)$ and Gbest $G_i\,(t)$ positions, respectively, r_1 and r_2 are real numbers within the range the range of zero to one, x, v and w are location, speed and inertia weight of the particle, respectively. An appropriate size of w gives improved optimum result. For a single iteration, inertia weight w is adjusted as in Equation (3.12).

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} iter \tag{3.12}$$

Where $iter_{max}$ represents maximum quantity of iterations and $iter$ is the present iteration while w_{max} and w_{min} stand for higher and lower boundaries of inertia weights, respectively. The position of individual particle is updated via distance from Equation (3.13).

$$x_i\,(t+1) = x_i\,(t) + \chi v_i\,(t+1) \tag{3.13}$$

where x_i refers to position of the particle in the study and corresponding speed v_i and χ is a constriction factor which is a velocity limiting factor.

Inertia weight has huge impact on the assembly of the PSO calculation. The impact of the first velocities on the common speed is instructed by inactivity load. A major latency weight offers help for reasonable generally search though a less worth of w helps the nearby examination. Mental boundary C1 draws in the particles in heading of Pbest while C2 draw in the particles to Gbest (Mwakitalima *et al.* , 2021). Table 3.7(a) indicates general procedure for MATLAB implementation of the PSO algorithm.

This article is assisted by financial improvement of discrete independent SPV with battery capacity as situation 1 and DG as situation 2 frameworks separately. The goal work is to limit all out NPC utilizing condition (1). Requirements are unwavering quality equivalents to 100 % (Sufficient battery stockpiling independence and high daylight with restricted variety), condition of charge (SOC) equivalents to 30 %, and profundity of release (DOD) has been expected equivalent to 85%.

Table 3.7: General procedure for MATLAB implementation of the PSO algorithm

Steps for the PSO coding process in MATLAB
Initialization of the problem with PSO parameters
Initialization of the particles
Calculation of fitness function
Computation for Pbest and Gbest 1
Stopping and storage of the global best value (Gbest) if criteria have been attained or if not, updating velocity and position of individual particle

Input boundaries for the two situations are organized in Tables 3.8, 3.9, 3.10,3.11, and 3.12 In this review, absolute NPC's independent SPV framework (first situation) and DG set (second situation) are $ 2089 and $ 19 488 individually. Table 3. 8 shows summed up enhancement consequences of HOMER versus PSO for SPV framework and DG designs. The NPC's acquired in PSO calculation are not exactly that of HOMER pro software. Figure 3.9 portrays convergence of NPC optimization using the PSO technique for Scenario 1.

Table 3. 8: Input variables for SPV panels

Input parameter	Value
Installed capacity	1.8 kW
Capital cost	$ 1822
Replacement cost	0
O & M	0
Efficiency	95%
Renewable fraction	100%
Fuel cost	0
Life time	25 years

Table 3.9: Battery storage input parameters

Input parameter	Value
System voltage	24 V
Battery capacity and Qty.	Nominal voltage 12V, 4 in quantity @ 1kWh, 2 in series and 2 strings,
Capital cost	$ 400
Replacement cost	$ 400
O & M cost	$ 0
Efficiency	75%
Life time	10 years
Autonomy	36 hours

Table 3.10: Converter input parameters

Input parameter	Value
Capacity	0.4 kW
Capital cost (ICC)	$ 250
Replacement cost (RCC)	$160
O&M cost (OPMC)	$0
Life time	25 years

Table 3.11: Input parameters for the PSO approach

Input parameters	Value
Acceleration C_1	2.01
Acceleration C_2	2.02
Random numbers r_1	0.5
Random numbers r_2	0.5
No. of iterations	100
No. of population	10
Annual real interest rate	0.03
Optimal solution	0.000001
Constriction factor	0.6
Max. weight maximum ($W_{max.}$)	0.7
Max. weight minimum (W_{min})	0.4
Salvage value	0

Table 3.12: Summarized optimization results between HOMER versus PSO for standalone solar PV system and DG configuration

Economic Parameter	Standalone SPV system SPV +Battery storage (Scenario 1)		DG system (Scenario 2)	
	HOMER	PSO	HOMER	PSO
NPC ($)	3,013	2,089	28, 116	19, 488

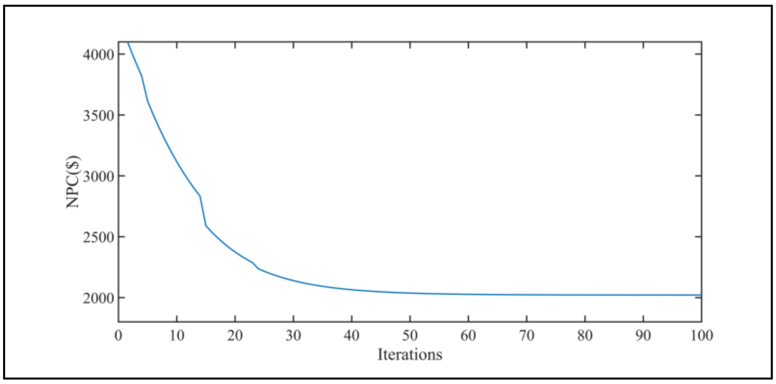


Figure 3.11. Convergence of NPC optimization using the PSO technique for Scenario 1(Mwakitalima et al.,2021)

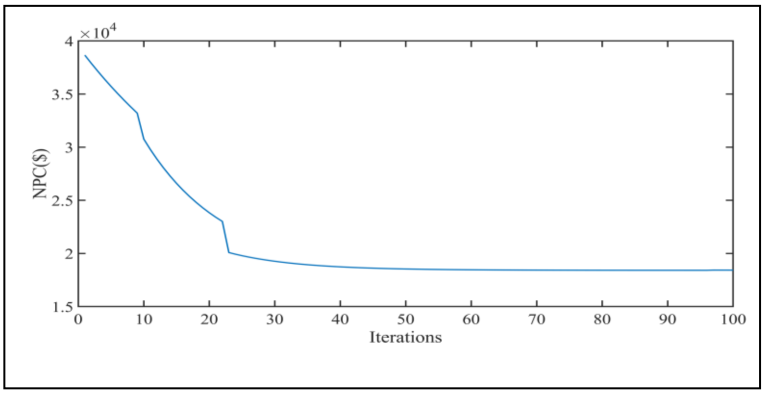


Figure 3.12. Convergence of NPC optimization using the PSO technique for Scenario 2 (Mwakitalima *et al*.,)

Results acquired by HOMER pro software are classified in Table 5 show that independent sun based PV framework is both more affordable and contamination than DG set. Moreover, the correlation of results between HOMER stag and PSO approach as classified in Table 8 shows that NPC's for independent SPV and DG have been additionally decreased in PSO technique. Figure 3.10 describes NPC graph for standalone PV and DG systems optimized using both HOMER and the PSO technique. Similarly, the upsides of absolute COE obtained by HOMER programming are more prominent than the qualities carried out in PSO procedures. In the situation 1 (Solar with battery capacity), absolute COE in the HOMER software and PSO approach are $ 0.397/kWh and $ 0.27/kWh $ individually. In Scenario 2 (DG), absolute COE got by HOMER pro software and PSO method are $ 3.71/kWh and 2.57 $/kWh individually. Moreover, after effects of the two situations 1& 2 and advancement strategies show that there is a drop altogether COE in the PSO procedure for somewhere around 69 %.

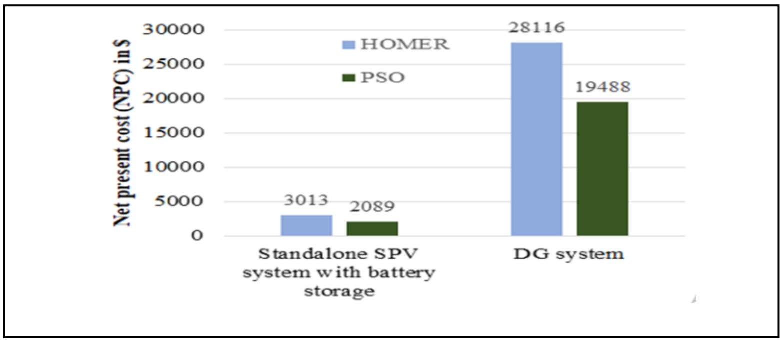


Figure 3.13. NPC graph for standalone PV and DG systems optimized using both HOMER and the PSO technique (Mwakitalima *et al*., 2021).

Figures 3.11, 3.12, and 3.13 show the convergence of COE optimization using the PSO technique for scenario 1, the convergence of COE optimization using the PSO technique for scenario 2, and the plot of COE for stand - alone solar PV systems and DG structures optimized using both the HOMER software and the PSO technique.

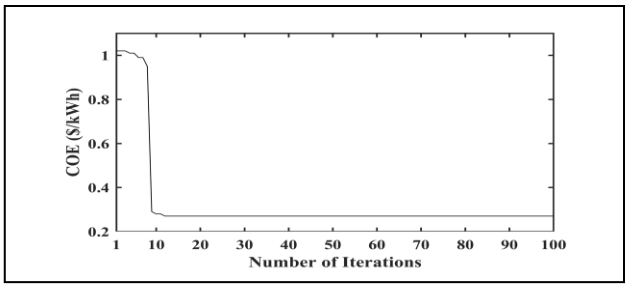


Figure 3.14. Optimization of COE using the PSO technique for Scenario 1 (Mwakitalima et al., 2021).

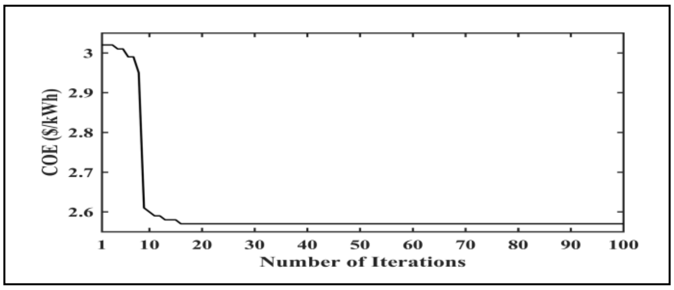


Figure 3.15. Optimization of COE using the PSO technique for Scenario 2 (Mwakitalima *et al.*, 2021).

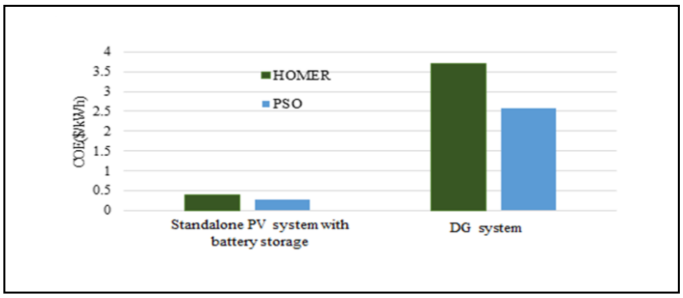


Figure 3.16. COE graph for independent PV and DG systems optimized using both HOMER software and the PSO approach (Mwakitalima et al., 2021).

3. 5 CONCLUSIONS AND RECOMMENDATIONS

This paper breaks down specialized and non-specialized viewpoints with respect to the age of power by sun oriented energy. The two angles are significant for detailing administrative casing work and key long haul energy arranging of rustic charge. The article has, through SWOT examination, talked about broadly the qualities, shortcomings, open doors and dangers with respect to the utilization of independent SPV frameworks for producing power in the country. The paper has expounded the open doors and difficulties of sun oriented based frameworks.

Then, at that point, the article has likewise introduced the consequences of techno-monetary and natural effect practicality investigation of independent SPV framework to satisfy energy need of the chose site. This study has given significant energy information in regards to sunlight based energy potential and financial aspects fundamental for smooth execution of independent SPV projects for rustic families in the proposed site. This might be embraced too in other provincial regions overall with comparative climate.

In view of this assessment, following suggestions are made for better utilization of independent SPV systems in the country:

- Legislature of Tanzania ought to keep on advancing sustainable power including solar PV system
- Better institutional and administrative system specific to solar PV innovation ought to be upgraded
- It is necessary to maintain a favourable market environment for solar PV systems
- Upgrade of specialized and administrative capabilities ought to be fulfilled
- Increasing large-scale solar PV is essential to reduce GHG emissions and provide socioeconomic benefits under the Kyoto Protocol's Clean Development
- Local research and development skills for renewable energy technology should be strengthened
- A large centralized infrastructure, as well as a portfolio of unique solar PV technology, must be offered
- A specific feed-in-tariff (FiT) for solar PV modules is required
- Subsidies and tax exemptions on all solar PV devices should be provided to raise overall utilization of the use of solar PV technology
- A substantial financing method scheme utilizing soft loans should be made available
- In this study, two separate technologies, standalone SPV and DG, are applied for rural electrification in the Tanzanian context.

3. 6 FUTURE RESEARCH WORK

Standalone solar PV system and DG can be integrated and by using real time approach and/or AI optimization algorithms techno-economic performance analysis can be implemented.

CHAPTER 4

TECHNO-ECONOMIC FEASIBILITY ANALYSIS OF SMALL WIND TURBINE ELECTRIC SYSTEM (SWTES)

4.0 GENERAL

Renewable energy sources will play a growing role in electricity production in the next millennium. They not only help to reduce greenhouse gas emissions, but they also give much-needed adaptability to the mix of electric multiple sources by reducing reliance on fossil fuels . Because of their ubiquity, abundance, and sustainability, solar and wind energy are the most important and necessary renewable energy supplies for sustainable energy. Wind is one of the renewable energy resources that can be used for electricity generation and for pumping applications (Gielen *et al*., 2019).

When wind is blowing at high speeds, it possesses a significant quantity of kinetic energy. When kinetic energy passes through the wind turbine blades, it is transformed to mechanical energy, which rotates the wind turbine blades and the attached generator, producing electricity (Bairwa ; Chaudhuri *et al*., 2022).

4. 1 FACTORS AFFECTING THE PRODUCTION OF WIND POWER

Wind turbine power generation can be affected by the following factors: wind speed, air density, and the surface skimmed by the rotor blades. The above-mentioned component clearly influences the wind turbine's electricity production, as seen in Figure 4. 1 (Muthu and Victor, 2014). Following are three types of factors the wind power:

(i) **Wind speed (V):** There are four types of wind speed, namely, starting speed (Initial rotational speed of the rotor and blade assembly), cut-in speed (minimal airspeed at which a wind turbine will produce useable power), rated speed (Minimal air speed at which the wind turbine produces its rated power) and cut-out speed (Most wind turbines cease electricity generation and shut down at large windy conditions). Power output from the wind system is directly proportional to wind velocity. The higher the speed the higher the output from the wind (Muthu and Victor, 2014).

(ii) **Air density (ρ_{air}):** The more thick the air, the further energy the turbine receives. The density of the air changes with altitude and temperature. At higher elevations, air is less heavy than at sea level, and hot air is less heavy than cold air. If all else is same, turbines does generate more energy at smaller elevations and in areas with cooler average temperatures (Muthu and Victor, 2014).

(iii) **Swept area of turbine machine (A):** The greater the sweeping area (the region through which the rotor revolves), the more wind power is captured by the wind turbine. Because swept area equals to $\pi D^2/4$, while D stands for the rotor's diameter, a little increment in length of a blade results in a bigger gain in turbine output (Muthu and Victor, 2014).

Global climate change is causing a worldwide lack of water supply. Water scarcity is particularly severe in developing-country rural sites (Hanjra and Qureshi, 2010; Mwakitalima et al., 2020). Water for consumption and agricultural uses is in short supply, especially during dry seasons. As a result, there is a need to expand access to safe water supply infrastructure through renewable energy resources including wind energy resource. Community-based systems are being implemented in Tanzania *(*Mwakitalima *et al.*, 2020;Jiménez Fernández de Palencia and Pérez-Foguet, 2011). Hand-powered pumps, mechanical windmills, and diesel-powered generators are examples of these systems (Mwakitalima *et al*., 2020). These are big projects with the following demerits:

- Requiring a large initial capital investment
- It takes a long time to implement them
- They are typically centralized and positioned far from many houses, and women's safety is rarely guaranteed
- Because it is dependent on human effort, only small volume of water might be obtained.

Non-dispatchable energy systems including wind energy resources are being used at a low rate in the country. Most of windmills are gradually being constructed in the nation for community-based water supply systems. The majority of the systems are at various phases of planning and implementation. Wind electric based pumping systems for family-level wind-based energy systems are being installed in a limited number of locations (Mwakitalima, Rizwan et al. 2020).

Merits of wind electric-based pumping systems are described as follows (Mwakitalima, Rizwan et al. 2020):

- Simplicity
- Versatility

- Higher loads
- Capability for utilization sites to be positioned far from the well via power cable

Demerits of Wind electric-based pumping systems are described as follows (Mwakitalima, Rizwan et al. 2020):

- Electric systems require a greater capacity of renewable energy supplies
- Durability and cost-effectiveness must be carefully considered
- There are environmental concerns such as bird mortality , visual effects, turbine noise, land impacts , and communication interferences

Wind turbines are classified based on their axis position and total generation capacity. There are two types of wind turbines based on their axis: HAWTs (Horizontal axis wind turbines) and VAWTs (Vertical axis wind turbines). HAWTs are frequently employed due to their ease of energy conversion and high power output. Wind turbines are divided into four types based on their generation capacity: micro, small, medium, and giant (Mwakitalima *et al.*, 2020) . Micro-wind turbine systems can generate power ranging from 20W to 500W and are used to charge recreational vehicles and batteries on sailboats (Mwakitalima *et al.* 2020). For residential applications, small wind turbine systems run at wind speeds of 3-4 m/s and are linked to batteries. Medium-sized wind turbines have installed capacities ranging from 20 to 300 KW and are employed in a variety of applications (Mwakitalima *et al.*, 2020). Large scale wind turbine installations with MW generation capabilities are available. Residential-based systems typically include a rotor, generator, and balance of system (BOS) components like as controllers, inverters, and batteries (Mwakitalima *et al.*, 2020). Guyed towers are commonly used in home wind energy systems due to their low cost and ease of installations (Mwakitalima *et al.*, 2020).

This study attempts to bridge up the gap of generating power using SWTES multiple appliances of water and electricity supply systems at a farmer's residence in Tanzanian environment (Mwakitalima *et al.*, 2020). The goal of this effort is to investigate the viability of generating energy via SWTES for powering pumping station for the peasants' dwelling and household electrical appliances located at Simboya village, Mbeya rural district in Tanzania (Mwakitalima *et al.*, 2020). For economic comparison, the TNPC or Life Cycle Cost (LCC) technique is utilized. The simulation and determination of optimal configuration (At the lowest TNPC) is carried out using the HOMER pro software.

4. 2 AREA OF STUDY AND METHODOLOGY

This part of this report includes a brief summary of the study's chosen location, as well as its energy profile evaluation. This section examines renewable energy supplies and electrical demand as crucial factors in the design of any electric producing plant. Precipitation at the chosen site influences the performance of water pumping stations and is thus taken into account in the design.

4.2.1 Area of Study

The description of the profile of the area under study is same as explained in the Section 3.3.1. Agriculture and livestock sectors are important economic activities in this area. The River Shongo provides potable water as well as small irrigated areas owned by individual residents. This river's water source is used by the neighbouring village of Ikukwa. The river's water flow is redirected into small plots due to gravitational force. The majority of the Mbeya region, including Simboya village, receives a lot of rain every year. Unfortunately, a considerable percentage of rain water is not gathered for dry season applications, resulting in a scarcity of water. During the dry season, the Shongo River's water flow is insufficient to adequately support agricultural irrigation. Furthermore, there is no grid connectivity in this area of study. Water supply can be ensured through the use of distributed generating electric systems. In this work, a feasibility study is conducted to determine the feasibility of supplying water supply for agriculturalists' residences in Tanzania utilizing a wind electric power system. Furthermore, the power generated by this system will be used to power the famer's home (Mwakitalima *et al.*, 2020).

4.2.2 Methodology

This part of this Chapter 4, presents the assessment of wind energy resource, load demand and climatic conditions.

4.2.2.1 Renewable energy resource

NASA-SSE provided data regarding Simboya village's renewable energy resources. Because the monthly average wind speed at 10 m is insufficient for electricity generation at this location, measurements are gathered at a height of 50 m to account for wind speed. Air velocity is 4.78 m/s and highest temperature is 24.9°C on a scaled yearly basis. This yearly wind velocity is adequate for minor wind power electricity generation. Rainfall data was received from TMA (TMA, 2019)) at the Mbeya Weather Station branch (Mwakitalima *et al*., 2020). Table 4.1 displays gathered data for energy resources and climatic profiles whereas Figure 4.1 depicts the potential wind energy resource for the proposed site.

Table 4. 1: Gathered data for energy resources and climatic profiles ((Mwakitalima *et al*., 2020)

Month	Velocity (m/s)	Min temp (°C)	Max temp (°C)	Rainfall fall (mm)
Jan	3.15	15.6	24.4	200.9
Feb	2.94	15.1	25.6	217.3
Mar	3.3	15.5	26.4	130.8
Apr	4.56	13.9	23.6	106.2
May	5.17	9.2	22.5	13.1
Jun	5.49	7.2	22.1	0
Jul	5.87	6.6	22.1	0
Aug	6.03	8.4	23.8	0
Sep	6.14	9.5	26.0	0
Oct	5.98	12.7	28.1	6.2
Nov	5.01	14.7	28.0	132.5
Dec	3.77	15.3	26.2	236.6

V denotes wind velocity at 50 meters, Min temp denotes minimum temperature, and Max temp denotes maximum temperature

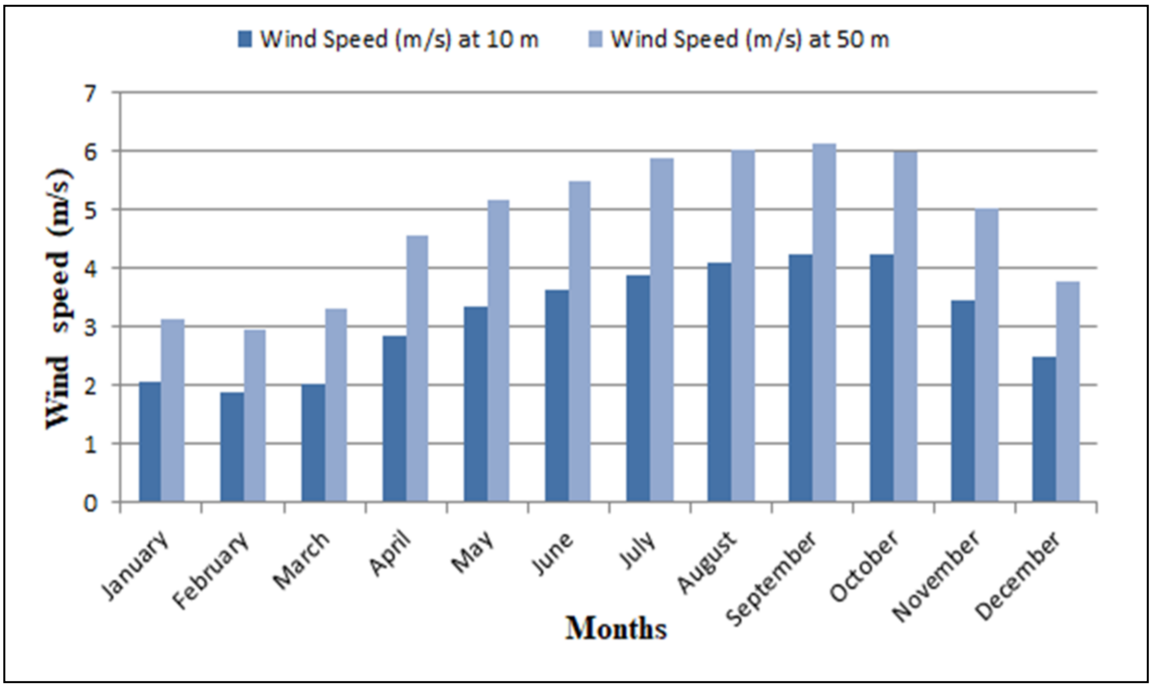


Figure 4.1. Potential wind energy resource for the proposed site (Mwakitalima *et al*., 2020)

4.2.2.2 Analysis of energy demand profile

The family's primary services include water supply, electricity, and cooling/heating. In this study, the demand for water and energy supply for peasant households is estimated. Heating and cooling services are not included. As a result, the demand profile analysis of the home is divided into two categories: water and electricity demands for the peasant's family. Water supply demand estimation is separated into uses such as family usage, irrigation for small plots, and animals. Additionally, the electrical load requirement for residential electric appliances is evaluated. In other words, the wind-powered system is meant to power pumping equipment and domestic appliances (Mwakitalima *et al.*, 2020). Figure 4. 2 shows a demand profile study for a typical peasant's home. The section that follows gives a demand profile analysis for water and electrical supplies for the peasant's home.

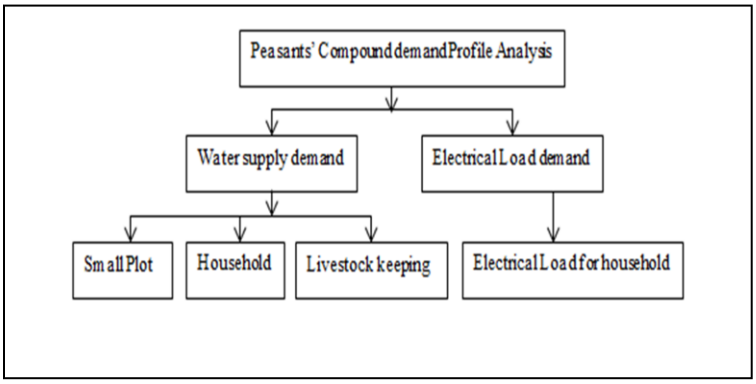


Figure 4.2. Demand profile study for a typical peasant's home (Mwakitalima *et al.*, 2020)

I: Water demand analysis for sizing electric water pumping equipment

The amount of water required for a little irrigated plot, family internal usage, and livestock maintenance for the peasant's home is estimated. A variety of factors determine the amount of water used for irrigation, including crop type, soil type variance, soil preparation, irrigation methods, precipitation, humidity, and cloud covering. Nevertheless, rainfall is a major factor influencing the quantity of water for small irrigated agriculture. The dry season, from June to September, has the highest water requirement for irrigated plots (Mwakitalima, Rizwan et al. 2020).. The following information is critical for evaluating the amount of water needed to irrigate a perennial plant such as sugarcane. Tables 4.2, 4.3, and 4. 4 depict daily water quantity for irrigated area, daily amount of water required for animal care, and daily water use of a peasant home

Table 4.2: Daily water quantity for irrigated area (Mwakitalima *et al.*, 2020)

Parameter	Specific assumption	Units/ remarks
Size of irrigated area	2	Acres
Area of plant spacing	1 m × 1.5 m = 1.5	m^2
Number of plants per acre	4026.86/1.5= 2685	quantity
Total number of plants for 2 acres	2685 × 2= 5370	quantity
AVR max. amount of water at dry season	20	Litres/ plant/ day
Water for irrigation in rainy season	0	Litre/plant/day
Amount of water for irrigating 2 acres per day	20×0.001×5370 = 107.4	m^3/day

Table 4.3: Daily amount of water required for animal care (Mwakitalima *et al*., 2020)

Specific livestock	Quantity	Assumed water consumption (m^3/animal/day)	Total consumption (m^3/day)
Cows	10	0.04	0.4
Oxen	2	0.03	0.06
Calves	5	0.02	0.1
Pigs	10	0.015	0.15
Sheep	20	0.008	0.16
Goats	20	0.008	0.16
Poultry	400	0.0002	0.08
		Total	1.11

Table 4. 4: Daily water use of a peasant home

Family member	Parents	Children	others	Persons per household
Number	2	3	2	7

Assuming that the basic daily per capita consumption of water in rural Tanzania is 25 litres/person (Mwakitalima *et al*., 2020).

. This volume of water is used by a person on a daily basis for drinking, laundry, and showering. As a result, the total amount consumed by the family equals the product of per capita water demand multiplying the number of people in the household (Mwakitalima *et al*., 2020).

Thus, total water use is 25 litres/person/day 7= 175 litres/day = 175 x 0.001= 0.175 m3/day

Total water use = 107.4 m3/day + 1.11 m3/day + 0.175 m3/day

The overall distance between the pumping and discharge levels is referred to as the head. The head of the pumping equipment is considered to be 15 m in order to assess its capacity. The pump's size was determined using equation (4.1).

P = Q g H ή (4.1)

Where P is the power transferred to water, Q is the flow rate in cubic metres per second, is the water density, g is the acceleration of gravity, and H is the head needed to raise the quantity of water to the water tank, and ή is the efficiency of the system.

Therefore, P = 0.0013 $m^3/s \times 1000\ kg/m^3 \times 9.81\ m/s^2 \times 15\ m = 191.3\ W$
Pump shaft efficiency = 100 percent power output/power input

Assumptions were made for the pumping system of water: A water pump's combined efficiency is the sum of its three component efficiencies. The aggregate efficacy of the pumping system was estimated using equation (4.2) (Mwakitalima *et al.*, 2020).

The overall efficiency of the assembly is 0.95* 0.85 * 0.75 = 0.61 (4.2)

Power input = Power output / combined efficiency of component assembly. Table 4.5 portrays Kirloskar Brother Limited's motor choices and specifications.

Table 4.5: Kirloskar Brother Limited's motor choices and specifications (Mwakitalima *et al.*, 2020)

Pump model	Power (KW/hp)	Voltage (Volts)	Head (m)	Discharge LPM
KS4F-1508	1.1 / 1.5	240V , 50 Hz	22	135

II: Household Electrical Load Analysis

In addition to the electric pump unit, an electrical load study for the peasant's residence is undertaken. The total load demand is calculated by combining the different types of loads (Mwakitalima *et al.*, 2020). Table 4.6 shows estimated overall electrical load for a peasant's home

Table 4.6: Estimated overall electrical load for a peasant's home (Mwakitalima *et al.*, 2020)

Appliance	Rating (W)	Qty	Duration (h)	Tot. power (W)	Tot. energy (Wh)
Energy saver lamp **I**	2	4	5	8	40
Energy saver lamp **II**	2	4	12	8	96
Fluorescent lighting	5	1	6	5	30
Television set	100	1	6	100	600
Refrigerator	300	1	12	300	2400
Phone charger	7	3	2	21	42
Electric pump	1100	1	5	1100	5500
				1.542	8,708

GROUP **I** stands for indoor illumination, and GROUP **II** stands for outdoor lighting

Based upon electric power utilization, the electrical load for pumping system is determined and distributed over a twenty-four hour period. The load factor in dispersed rural areas is low; hence a load distribution is implemented to increase it. Before the full examination using HOMER pro software, the evaluation has been carried out in MS Excel worksheets by customizing data templates. During the rainy and dry seasons, the baseline peak loads are 0.045 kW and 0.262 kW, respectively (Mwakitalima *et al.*, 2020). Due to an increased irrigation, the electrical load during the dry season is larger than during the wet season. During the wet season, no electricity is necessary for irrigation (Mwakitalima *et al.*, 2020). SWTES provides power for electrical appliances and the interior use of the house's water supply.

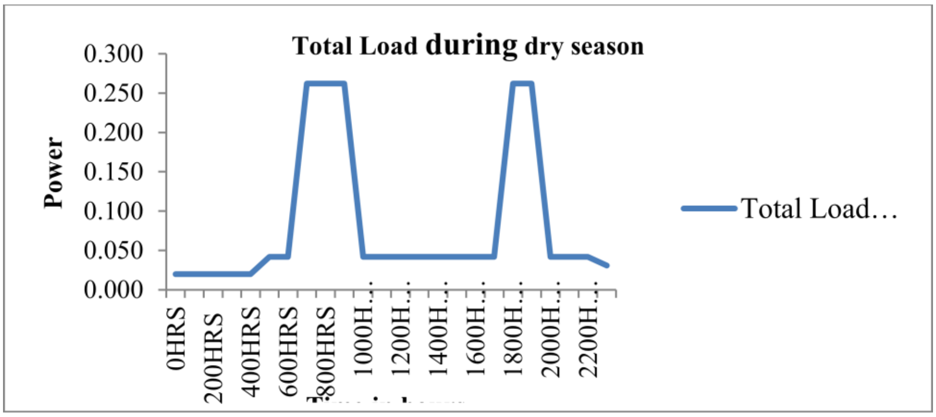


Figure 4.3. Load profile of a day throughout the dry season (Mwakitalima *et al.*, 2020)

According to Table 4.1, the dry season lasts from June to September, with no rain, and the wet season lasts from October to May.

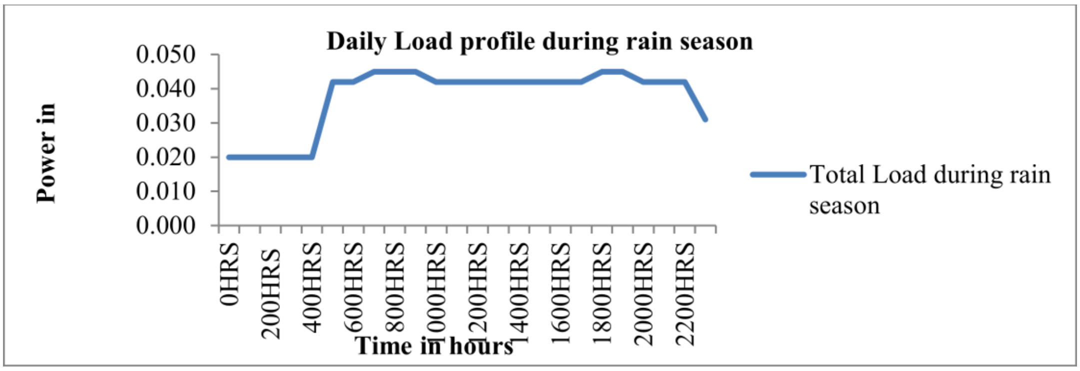


Figure 4.4. Load profile of a day throughout the rainy season (Mwakitalima *et al.*, 2020)

Calculating the accurate size for water storage tank

Figure 4.3 (a) - (b) depict electrical load distribution based on load profiles for domestic electrical equipment pumping system in dry and wet seasons from an excel sheet and a load profile synthesized using HOMER (Mwakitalima et al., 2020).

The capacity of a storage cistern is determined by multiplying the daily water requirements (Q) by the number of days (Nd) required to deliver a fixed supply of water. The volume of water tank is calculated using (4. 3).

Total storage system capacity, Ct = Q N d (4. 3)

As a result, Ct = 108.69 m3/day x 3 days = 326.07 m3.

Figure 4.4 depicts Block diagram of the SWTES structure, which supplies power to the water pumping plant and electric equipment for the peasant's dwelling

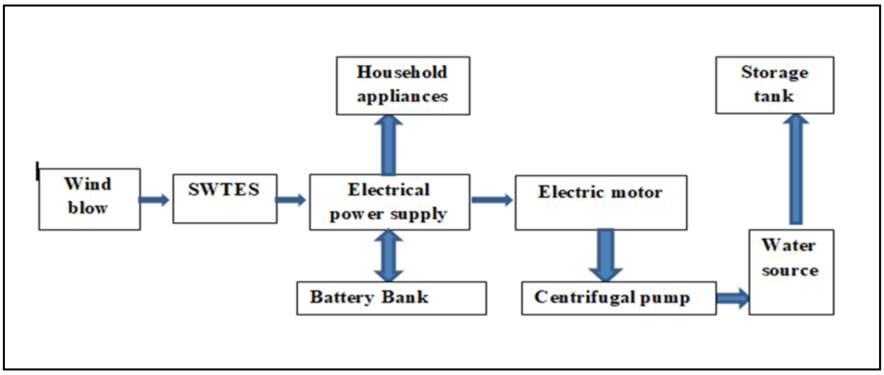


Figure 4.5. Block diagram of the SWTES structure, which supplies power to the water pumping plant and electric equipment for the peasant's dwelling (Mwakitalima et al., 2020).

4.3 DESIGN AND FEASIBILITY ANALYSIS OF SWTES

SWTES components include rotors, generators, charge controllers, inverters, and batteries. The power production of SWTES is determined by the density of the air, the swept area of the rotor, the wind speed, and the electric power of the (WT) wind turbine. Equation (4.4) calculates power based on WT (Mwakitalima *et al.*, 2020; Siddikov *et al.*, 2022).

Pw = 0.5* Cp *A* v3 (4. 4)

Where Pw denotes wind power output, is air density (kg/m^3), A denotes rotor sweeping area (m2), v denotes wind speed (m/s), Cp denotes wind power coefficient, and t denotes drive train efficiency. SWTES are small wind turbines with a rotor swept area of less than 200 m^2 (Mwakitalima *et al.*, 2020).

The HOMER pro software is used to obtain the best SWTES configuration. The system configuration must be both dependable and cost-effective. The system's cost-effectiveness and dependability are characterized by the lowest LCC. Yearly energy generation (YEG) is one of the key characteristics assessed by HOMER. Equation is used to calculate total yearly energy generation (Mwakitalima *et al.*, 2020).

Then, $\text{YEG} = 8\,760 * \int (P(V) * f\ (V) * dV)$ (4 .5)

Where,

- YEG stands for early energy generation in kWh with respect to a given wind velocity,
- P (V) represents electric power generated at a given wind velocity in watts, and
- f (V) refers to the wind velocity probability density function.

The Weibull distribution function offers a diverse set of wind energy resources. The Weibull distribution function is used to express wind velocity V. The function has two variables that can be used to determine wind potential: The scale factor c (m/s and the shape factor k (dimensionless). This distribution function is defined in (4.6) and (4.7) by the probability density function and the cumulative distribution function (Mwakitalima *et al.*, 2020).

$f(V) = k/c\ (V/c)^{k-1} \exp\ [-\ V/c]^{k}$ (4.6)

Cumulative distribution function,

$F\ (V) = 1 - \exp\ [-\ V/c]^{\ k}$ (4.7)

The distribution function has a constant value of k equal to 2. To compute k and c values in this work, analytical and empirical approaches were adopted for simplicity. According to the wind statistics collected, the summation of monthly averages is expressed as (Mwakitalima *et al.*, 2020):

$N = 12$, $\Sigma V = 57.41$, $\Sigma V^2 = 290.7095$, Mean velocity, $V = \Sigma V/12 = 57.41/12 = 4.78$ m/s

Nevertheless, Variance $\sigma^2 = 1/\ (N-1)\ [\Sigma V^2 - (\Sigma V)^{2}/N] = 1/\ /\ (12-1)\ [290.7095 - (57.41)^{2}/12] = 1.459$

The standard deviation, $\sigma = 1.21$, k and c are calculated using equations (4.8) and (4.9) respectively.

$k = (\sigma/\text{mean } V^{)\ -\ 1.086}$, (4.8)

Therefore, $k = (1.21/4.78)^{-\ 1.086} = 4.45$,

$c = [0.\,568 + (0.\,433)\,/k]^{\ 1/k} * V$ (4.9)

So, $c = [0.568 + (0.433)/4.45]^{1/4.45} * 4.78 = 4.36$ m/s

The capacity factor (CF) of a wind turbine is the amount of electricity produced by the system divided by the largest amount of electricity that could have been generated if the system had been operating at full installed capacity for the whole year, which is 8760 hours (Mwakitalima et al., 2020). To calculate CF, use Equation (4.10). Numerically,

$$\mathrm{CF} = 100 * \frac{\mathrm{YEG}}{\text{Installed generatiin capacity} * 8760} \tag{4.10}$$

The total (NPC) Net Present Cost is a parameter that indicates how long the project will last. NPC calculates the amount of money in $ now with a future cash flow discount to current value based on the specified discount rate I = 7.0 percent (Bank of Tanzania). Equation is used to calculate NPC (Mwakitalima *et al.*, 2020).

$$C_{\mathrm{NPC}} = \frac{\mathrm{TAC}}{\mathrm{CRF}\,(i,N)} \tag{4. 11}$$

Where TAC is total annualized cost, I denote discount rate, N denotes the number of years the project will be in operation, and CRF denotes capacity recovery factor. CRF is computed using the equation (Mwakitalima *et al.*, 2020)

$$\mathrm{CRF}\,(i, N) = i\,(1+i)/\,(1+i)^{N}-1 \tag{4.12}$$

HOMER software takes an average unit (kWh) cost of utilisable energy generated by SWTES as the levelized cost of energy (LCOE). The LCOE is defined as the total annualized cost of electricity divided by the total amount of electricity served or consumed. The LCOE is computed using (Mwakitalima *et al.*, 2020)..

$$\mathrm{LCOE} = \frac{\text{Total annualized cost}}{\textit{Total amount of electricity used}} \tag{4. 13}$$

[19]

RF (Renewable fraction) is the electrical energy fraction delivered as a load that is 100 percent derived from renewable energies (REs).

4.4 OPTIMIZATION RESULTS

In this study, the primary and deferred loads are combined to form the general AC electrical load for the proposed energy system. Due to the increased irrigation activities, electrical demand during the dry season is higher than during the wet season. As a result, the suggested system's configuration is based on the dry weather load. During the rainy season, the scaled maximum power and energy utilization are 1.48 KW and 11.26 kWh/day, respectively. Figure 4.5 depicts the proposed system's schematic architecture, while Figure 4.6 describes the WT power curve for off-grid SWTES.

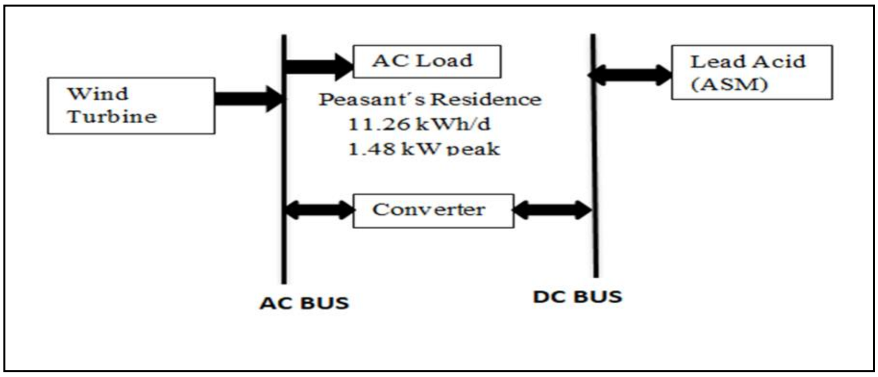


Figure 4.6. Configuration of off-grid SWTES

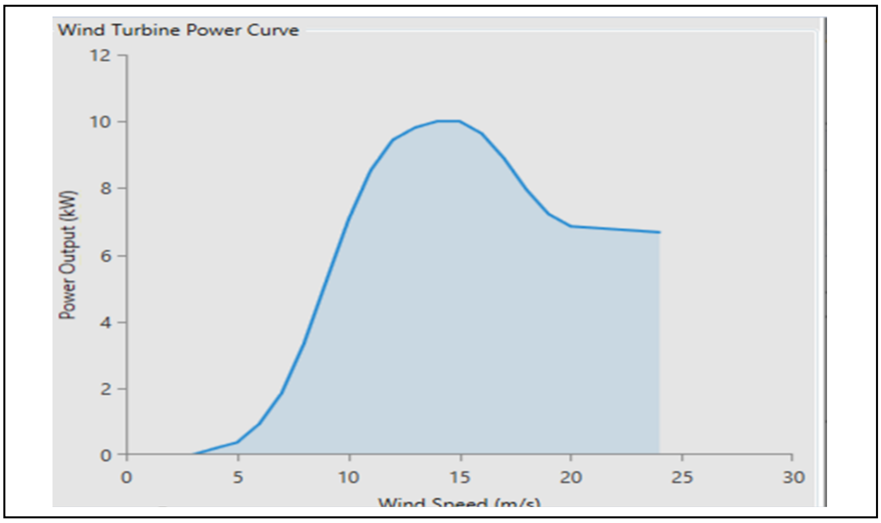


Figure 4.7. WT power curve for off-grid SWTES

4.4. 1 Optimal SWTES Components

Aside from the electrical load, the suggested system contains key components such as a wind generator, a battery bank, and a converter.

Table 4.7: Technical data for simulated SWTES and related miscellaneous input parameters

NAME OF COMPONENT	VALUE
GENERIC WIND TURBINE GENERATOR:	
Rated capacity (kW)	1-10
CF (%)	4.57
RF Wind Penetration (%)	97.3
YEP (kWh/year)	3999
Electrical consumption (kWh/year)	4 109
Hub height (m)	50
Altitude above sea level (m)	1700
Lifetime (years)	20

Average wind speed (m/s)	4.78
Availability losses (%)	2
Turbine performance losses (%)	3
Wake effect losses (%)	0.25
Electrical losses (%)	0.5
Other losses (%)	1
Shape factor, k	4.45
Scale factor, c (m/s)	4.36
Diurnal pattern strength	0.15
Wind speed duration (hours)	10
GENERIC LEAD ACID BATTERIES:	
Nominal voltage (v)	2
Nominal capacity (kWh)	1.03
Maximum capacity (Ah)	513
Number of batteries	4608
Number of strings	48
System voltage (v)	96
Initial stage charges (%)	100
Mini state of charge (%)	30
Degradation limit (%)	5
Anticipated life (Years)	2.93
Lifetime through output (kWh)	7297
Autonomy (hours)	9573
CONVERTER:	
Rated power (kW)	10
Peak output power (kW)	1.48
Inverter efficiency (%)	95
Rectifier efficiency (%)	95
Lifespan (hours)	15

Table 4.8: NPC details and expected expenses for simulated SWTES depending on specified components

	Name of components		
	Wind turbine generator	Lead acid batteries	Converter
Specific cost	Cost per Kw ($)	Cost per unit ($)	Cost per kW ($)
Capital cost	10 000	150	350
Replacement cost	10 000	100	350
O & M cost	400	10	10
System cost	**Type of key system costs**		
	Initial cost ($)	TNPC ($)	LCOE ($)
	29 400	106 273.80	1.58

Table 4.9: Summary of NPC costs for specified off-grid SWTES components

Component	WT 10 kW	Batteries	Converter	Miscellaneous	
Capital ($)	10, 000	14 400	3500	1500	29 400
Replacement ($)	4946.87	49 657.06	2064.51	0	56668.44
O&M ($)	6534. 36	15 682.71	1633.62	1796.98	25647.76
Fuel ($)	0	0	0	0	0
Salvage ($)	53 111. 54	1646 .81	484.02	0	5442.36
Total ($)	18 369.8	77892.96	6714.11	3296.98	106 273.8
%	17.3	73.3	6.3	3.1	100

Table 4.10: Economic considerations and limits

Economics / Constraints parameters	Value
Project lifetime (Years)	25
Nominal discount rate (%)	7
Expected inflation rate (%)	3.3
System capital ($)	1500
System fixed 0 & M ($/ year)	110
Capacity shortage penalty ($/ kWh)	0
Minimum annual capacity shortage (%)	1
Operating reserve, load current time step (%)	7
Minimum RF (%)	100
Wind power output (%)	100

Table 4.7 displays technical information for the modelled SWTES as well as related other input variables. SWETS has a YEG of 3999 kWh each year. Table 4.8 illustrates the overall price for modelled SWTES as well as the expected expenses based on specified components. SWTES' total NPC is $ 106 273. 80 and the LCOE is anticipated to be $ 1.58/kWh. Table 10 summarizes the total NPC cost per selected component for off-grid SWTES. The price of battery bank is $ 77 892. 96 (73.3 percent) greater than the price of WT, which is 18 369. 80. (17.3 percent). The converter costs $ 6713.11. (6.3 percent). SWTES has various charges totaling $ 3296.98. (3.1 percent). Table 4.10 shows the project's economics and restrictions. The project's lifespan is estimated to be 25 years.

4.5 COMPARISON OF OFF-GRID SWTES AND GRID EXTENSION

The economics of optimized off-grid SWTES are compared against Tanzania Electricity Supply Company's national grid extension (TANESCO). HOMER calculates the BGE (Breakeven grid extension distance), which specifies the LCOE in standalone systems, particularly off-grid SWTES, which are less expensive than a national grid expansion. The capital cost, operating and maintenance costs, and grid power cost are $ 9500/Km, $ 713/year, and $ 0.1/kWh, respectively. The BGE is 4.58 km, implying that for distances larger than this number, off-grid SWTES is less expensive than grid network from

TANESCO. Figures 4.7 and 4.8 show configuration of grid-connected SWTES and graph of BGE distance, respectively.

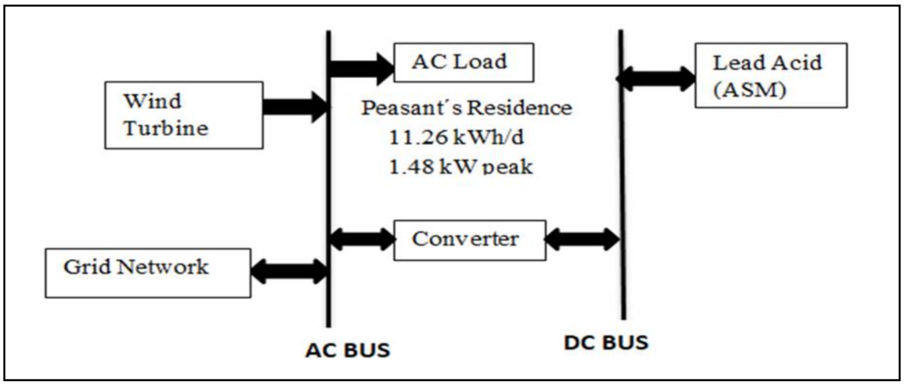


Figure 4.8. Configuration of grid-connected SWTES

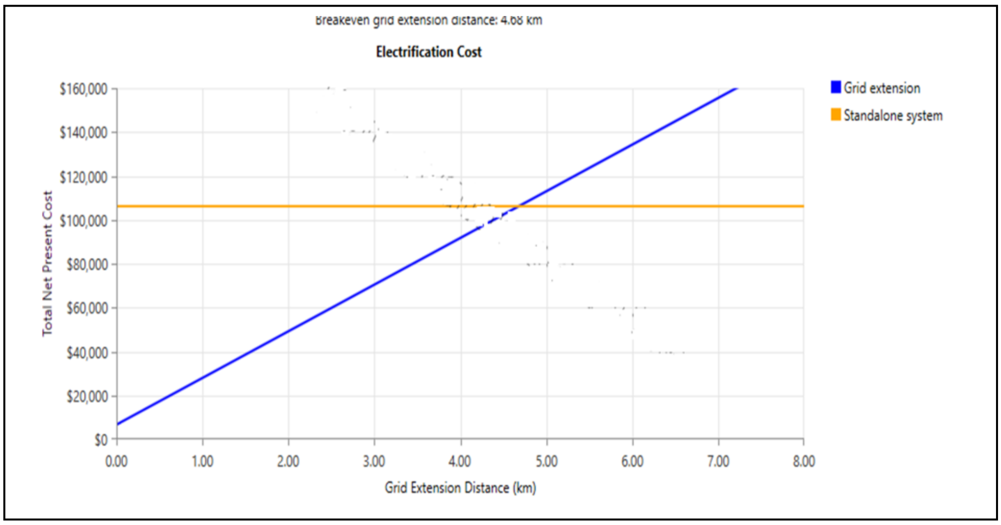


Figure 4.9. Plot of BGE distance

4.6 CONCLUSION

The generation of electricity from wind turbine systems is determined by various elements, including the capacity of wind resources, as well as practical and operational aspects. SWTES was designed in this study by taking into account the available wind pattern at the chosen rural site. Economic and technical assessment of envisaged off-grid SWTES for various electrical demands of a peasant compound in rural Tanzania was carried out. The simulated SWTES is designed to provide electricity and water supplies for residential and irrigation applications. Because of the high demand for water supply, especially irrigation, there is a larger need for power during the dry season than during the wet season.

SWTES was designed using the load profile during the dry season. In this study, the pumping system's deferred load was coupled with the electrical equipment to generate the main load.

The projected maximum load and daily utilization are 1.48 kW and 11.26 kWh/day respectively. For appropriate CF simulated SWTES, the capacity is more than the maximum power. It has components like a WT of 1- 10 kW, a 10 k W converter, and 4608 batteries. However, the volatile nature of wind energy resource is a significant disadvantage of this system. Off-grid SWTES necessitates a large quantity of batteries, which raises the cost. This project's lifespan has been set at 25 years. The NPC and LCOE are respectively $106 273.80 and $1.58. SWTES is actually less expensive than grid extension. SWTES is more viable once the BGE of 4.58 Km is exceeded.

4.7 FUTURE RESEARCH WORK

In future, the study can be enhanced by the analysis of integrating of more energy sources including grid power and using AI optimization techniques,

CHAPTER 5

TECHNO-ECONOMIC FEASIBILITY ANALYSIS OF AMALGAMATED SYSTEM OF SOLAR PHOTOVOLTAIC (PV)/BIOGAS/BATTERIES

5.0 GENERAL

In any culture, energy plays a significant role in providing high-quality socioeconomic services. Energy consumption increases social standard of living and facilitates economic activity productivity. The demand for power is well known around the world. The United Nations refers to it as "Goal 7" and describes it as a sustainable development goal. The goal is to ensure that everyone has access to reliable, affordable, up-to-date, and sustainable source of energy (Aslam *et al.*, 2021). Furthermore, fossil fuels are expensive, and whose reserves are limited and depleting. These nonrenewable fuels are also harmful to the environment. In other words, the use of fossil fuels contributes to pollution and climate change (Shahsavari and Akbari, 2018). Energy scarcity is a big issue in developing countries, especially in rural areas where there is no grid connection. Increased population and economic activities in these emerging countries contributes to an increase in energy imbalance. The majority of less developed countries address the rural energy gap by deploying diesel generators. The emerging economies in developing countries address the rural energy gap by deploying diesel generators. Due to the aforementioned concerns with fossil fuels, generating power with diesel generators is both economically and environmentally unsustainable. As a result, alternate energy sources are critical for long-term growth (Micangeli *et al.*, 2017). Similarly, Tanzania, as one of the SSA countries, has an estimated total population of 58 million, of which 20% are urban people and the remaining 80% are rural citizens. Approximately 30% of the country's population has access to the electric grid (Al *et al.*, 2019). A large proportion of the population lives in rural areas, where there is a significant demand for power, which is unfavourable. DG's have been used to address power supply inadequacies in rural and remote locations. Nonetheless, this rural electrification strategy is expensive and polluting (Dibaba, 2019). This energy scenario can be addressed by utilizing the country's significant renewable energy resources (Dibaba, 2019). Unfortunately, these energy sources' enormous potential is underutilized (Dibaba, 2019). Off-grid power systems for remote and rural areas can be powered by sustainable and renewable energy sources such as solar, wind, small hydro, and biomass. Renewable energies are inherently intermittent, resulting in variable power output. These renewable sources' reliability, energy management, and cost difficulties can be solved by using power storage equipment and a hybrid technological configuration (HRESS) to provide power for countryside applications (Babatunde *et al*., 2020). Furthermore, the feasibility of sustainable and renewable energy supplies varies widely. All sizes of HRESS are necessary for optimum operation. Thus, adequate HRESS size is necessary for proper performance and cost-effectiveness. The ideal size of HRESS is essential for proper operation.

Several researches on HRESS have been conducted in various areas throughout the world (Babatunde *et al*., 2020). The primary purpose of this research is to find the best HRESS configuration depending on local resources for distinct remote and rural areas in Tanzania. The paper provides an economic comparative analysis of biogas fuelled generator against DG in the hybrid solar PV system, with biogas generator being more cost efficient for replacing DG, which is limited in rural regions of the SSA region. The first phase of this study performs a techno-economic analysis using HOMER Software for the various configurations that are expected to generate energy at the proposed location and contrasts them using a long - term financial profitability known as Net Present Cost (NPC) over a 25-year period.

Such a study could be valuable for developing energy policies and making business decisions for the commercialization and deployment of hybrid biogas energy sources to provide supply of electricity in rural areas of the country. The methodology's precise aims are as follows in order to achieve this goal: (i) Trying to identify and proposing the rural location without grid connectivity (ii) Identifying and realising the potential of local renewable resources (iii) Evaluating the energy requirements for the suggested off-grid site (iv) Modelling, system design optimization, and selecting the optimum cost-effective HRESS.

Figure 5.1 indicates the comprehensive approach of the study. At the moment, the application of metaheuristic approaches is a relatively new subject that is being thoroughly investigated by a large number of researchers. In instance, according to the authors' experience and theoretical underpinnings, the bulk of HRESS investigations in Tanzania have been conducted out using HOMER software. Metaheuristic techniques' applications are limited or have yet to be implemented. As a result, and in accordance with current research trends, this study employs both HOMER pro platform and an innovative metaheuristic technique known as grey wolf optimizer (GWO). The GWO strategy is one of the AI optimization strategies that have proven to be effective. The GWO approach is deployed and evaluated by HOMER software in the second part of the project.

The breadth of this study does not allow for a comparison of all known approaches. Nonetheless, the use of GWO provides advantages such as ease, adaptability, the absence of derivation during the optimization process, and the avoiding of local optima due to the stochastic character of GWO (Yahiaoui *et al.*, 2017). The GWO technique is ideal for handling difficult non-linear, multi-adjustable, multi-modal function optimization issues. In short, the approach offers a high exploration capability and a good balance of global and local spaces (Nimma *et al.*, 2018).

5.1 RELATED THEORY

This section discusses the relevant theory of electricity supply to those populations residing in remote areas utilising renewable energy-based systems in order to enhance reliable electricity at both the international and national levels. The theory begins by highlighting the benefits of employing renewable power sources for providing electricity to rural areas in Tanzania, with a focus on the use of sunlight and biogas power sources. A comprehensive analysis of related literature is also conducted to examine the usage of SRER for rural electrification worldwide. The following is a summary of the review:

5.1.1 Tanzanian Survey on the Hybridization of Solar and Biogas Energy Sources

- In African nations including Tanzania, level of creating power utilizing environmentally friendly power advancements is low (Dibaba, 2019). A few investigations demonstrate that power age for country charge has been essentially zeroing in on little electrical burden for private, little business and hardly any institutional structures absent a lot of thought of useful purposes of power (Contejean and Verin, 2017). Electrical requirement in these premises for the most part is provided by means of single obtained sustainable power frameworks and are ordinarily made for lighting, cell phone charging, refrigeration and amusements. Single-obtained environmentally friendly power frameworks are not solid because of irregular nature and consequently there is a requirement for either energy capacity frameworks which are costly or crossover innovation. These frameworks offer valuable social types of assistance in off-matrix areas however with restricted useful purposes (Sen and Bhattacharyya, 2014; Ugwoke *et al.*, 2020). For the upgraded financial advancement in the provincial regions limited scope modern and road lighting loads should be remembered for expansion to private, limited scope industry, business and institutional electrical loads (Ugwoke, *et al.* 2020). This heap incorporates limited scope welding ventures, flour factories, little carpentry studio, and limited scope sewing enterprises. The useful purposes may likewise incorporate different areas like farming; transport and water system however in this work are disregarded. Thus, for the superior unwavering quality, cost-adequacy, natural advantages and useful purposes, HRESS is a reasonable decision (Ugwoke *et al.,* 2020; Al-Falahi *et al*. 2017). In the SSA area and all the more explicitly in Tanzania there is a high capability of biomass as creature misuse of which biogas can be tapped in for producing power by means of off-matrix HRESS (Ugwoke *et al.* 2020). The gigantic potential could be useful for the decrease of energy neediness in the district. Sadly, this potential from creature squanders stays unused. In the nearby degree of nation and by and large in the SSA countries there are not many examinations mixture biogas based electric frameworks (Ugwoke *et al.* 2020). This study attempts to interface the gap in the current writing. Furthermore, the public authority of United Republic of Tanzania through its innovative work foundations upholds on the age of power of such frameworks in the nearby locales with significant number of various animals species. This sort of help from the public authority is an inspiration for neighborhood specialists to work toward this path in for exploring the capability of producing off-network half breed biogas-based energy frameworks *(*Kemausuor, *et al*., 2018; Ugwoke *et al*., 2020). In a similar view, this study is done to answer such inspiration from the public authority. The plan of HRESS is primarily an area explicit relying upon neighborhood environmentally friendly power assets and electrical burden request (Elkadeem *et al.*, 2019). In view of the creators' perception and accessible writing, sun powered and battery frameworks hybridized with biogas generators are restricted in the country. Subsequently solar PV-biogas-battery capacity crossover framework is proposed. The framework is expected to give energy administrations to Simboya town situated in Mbeya Rural District in Tanzania. The town gets no power from public focal network which is known as Tanzania Electricity Supply Company (TANESCO). These kinds of systems are in research stages at various destinations and this specific examination work contributes in a similar track. Henceforth, before the turn of events and execution this framework should be examined to secure information about its true capacity and monetary support for the chose site and comparative area around the world.

5.1. 2 Global Survey of RES Use for Rural Electrification: Gaps and Comparative Study

Numerous studies have been carried out along this line and trend of advanced optimization techniques particularly metaheuristic approaches (Alba *et al*., 2013; Fernández *et al.* 2019). A large group of analysts has used a variety of simulation tools and approaches to study various forms of renewable energy sources for power generation by performing case studies in various locations, particularly in remote rural areas. Different locations have varying levels of SRES availability, as well as varying levels of renewable energy resource potential and load patterns (Alba *et al*., 2013; Fernández *et al*., 2019). This distinction necessitates feasibility assessments prior to the design and deployment of decentralized energy systems. Globally, there are multiple methods are used to investigate the designing and sizing the renewable energy based systems starting from classical, soft computing to modern techniques for instance, the current trend of applying nature inspired methods (Metaheuristic approaches), i.e. application of AI optimization techniques *(*Alba *et al.,* 2013*;* Fernández *et al*., 2019). Generally, researches and development regarding the use of renewable energy sources in Tanzania is at early stages and related configurations, for instance, hybrid biogas – energy based systems are advocated by Tanzanian government are currently being researched, and no any such kind of a system is operating locally (Musonye *et al.*, 2020). An integration of multiple energy sources to build up is a complicated task which needs thoroughly investigation (Technically and economically) *(*Zhou *et al.*, 2010, Hobbie *et al.*, 2022). Therefore, this present study is in alignment of the trend for exploring local renewable in Tanzanian environment so as address the energy shortage in rural areas as well as to address the challenge of environment concern from using the detrimental energy sources, i.e. fossil fuels. Comparatively and precisely, most of the researches regarding decentralized renewable energy based systems in Tanzania have been carried by HOMER platform. In the light of the survey on many case studies globally and locally, there are many methods starting from traditional to advanced ones have been used to design and size the systems. Here it is beyond the scope to of this study provide an all-inclusive comparative analysis based on the applicable methods of designing the systems.

This particular research endeavour attempts to fill the gaps mentioned above by utilizing soft computing and AI optimization methodologies. HOMER is widely used in SSA nations, including Tanzania, in a variety of research, with limited uses of AI optimization methods and hybrid biogas-based systems. So, in this study, soft computing (MS excel program and HOMER software) and as well as AI optimization tools (GWO technique) were used to perform a technical-economic analysis of a proposed off-grid HRESS for providing electricity to the study field.

Similarly, the analysis comprises minimizing the total NPC and its accompanying LCOE of the off-grid HRESS in "Simboya village," a rural area in Tanzania's Mbeya region. In the first place, a techno-economic feasibility investigation of HRESS was carried out utilizing the HOMER platform and the GWO technique.

5.2 OUTLINING THE CONTRIBUTION OF THE STUDY

Based on the comprehensive literature, SRES's have large potential for the provision of electricity to the isolated areas worldwide. The main contributions of this research are presented as follows:

In most poor nations, notably in the SSA region, where the site under research is located, hybrid biogas electric systems are scarce and in some countries are not available at all. The majority of the region's modest energy systems generate biogas for limited applications including food preparation, lighting, and heating (Amuzu-Sefordzi, Martinus et al. 2018). As a result, this study presents an optimization issue for a newly design of optimal off-grid HRESS that combines SPV and biogas energy sources to provide electricity in rural locations of Tanzania.

- The work describes the optimization of system sizing utilizing HOMER pro software and a recently built metaheuristic research platform known as grey wolf optimization (GWO). It specifically involves the application of the GWO technique while taking system reliability into account.
- The study also presents a novel method of presentation for graphing the total NPC and LCOE in relation to BGR distance using systems of equations.
- This study compares the economics of hybrid SPV-BIOG-BATTERY, SPV-DG-BATTERY, and DG systems versus BGE distance in Tanzania. Biogas generators are being investigated as a replacement for DG in hybrid SPV systems. In addition, the article expands on the comparative analysis of GHG emissions amongst the aforementioned energy producing sources.

- This study raises awareness, enlightens, and serves as a bridge of missing energy statistics in most rural and remote parts of developing nations, including Tanzania, about the generating costs, performance, and use of hybrid biogas- fuel based power systems.
- The research describes the identification, exploration, and deployment of livestock-poultry biomass (bio-wastes) for energy shortfall solutions, as well as the issues of environmental pollution (odour) caused by animal and poultry wastes in the study area.
- Also, this paper offers sensitivity analyses performed with HOMER pro software and the GWO approach.

5.3 METHODOLOGY

5. 3.1 General Explanation

Prior to investigating HRESS utilizing HOMER pro platform, there are two crucial and vital components that are required for any design of an electric system, namely the availability of RES's as well as their potential and projected energy consumption for the site of interest. Knowing the amount of energy at a specific location is useful since it tells us how much energy will be generated. Commercial, domestic, small-scale industrial, institutional, and street lighting loads are categorized in this study. Agriculture and irrigation requirements are not taken into account. The explanation for this is that rural residents in the research region do not require refrigeration to cool agricultural items. Irrigation works for the intended site's fields are carried out by diverting the River Shongo and minor streams of water pouring down under gravitational attraction from the highlands surrounding Mt. Mbeya.

This river sustains the life and irrigation of the villages of Simboya and Ikukwa. This rural location does not require any electrical usage for transportation. HRESS components are chosen in accordance with the available potential of SRES's. The survey was carried out using site visits, ward development records, comprehensive literature, interviews, questionnaires, measurements, and internet browsing. All necessary data for required off-grid HRESS components, loads, RES, and charges are collected as input data in the HOMER pro software optimization process.

HOMER, which stands for Hybrid Optimization Model for Electric Renewable, is one of the analytical tools. During the optimization, the ideal configuration of HRESS is obtained for supplying sufficient electricity at the lowest NPC (Life Cycle Cost, abbreviated as LCC)

HOMER can perform sensitivity and GHG emissions studies in addition to optimization process.

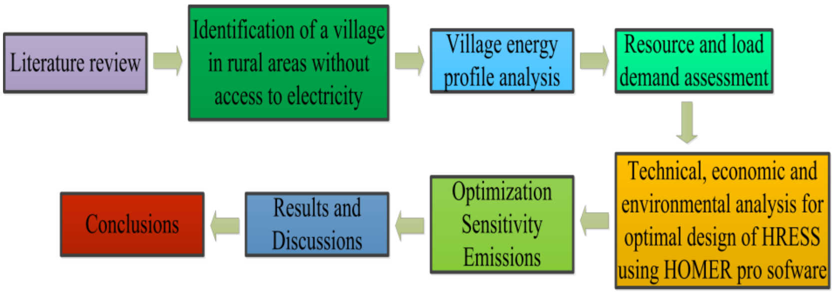


Figure 5.1. Comprehensive research approach

The structure of any hybrid system is determined by the local renewable energy supplies and load demand of the specific site. According to the fieldwork conducted in the study area, there is a great potential for solar and biomass (animal waste and chicken droppings) energy resources, so SPV and biomass (biogas) power generating units have been deployed. In addition, for proper operation, extra hardware such as electricity regulating electronic devices, electrical load, and battery energy storage system are required. DG is typically utilized in HRESS as a backup to improve system performance under peak loads and in the unavailability of renewable energies. In this case, a biogas electric electricity generating unit is used to back up the system instead of ordinary back-up source of DG. This planned HRESS is 100 percent renewable, making it both cost efficient and environmentally friendly.

Figure 5.2 indicates schematic arrangement of the off-grid HRESS for the proposed site. Optimization is used to create optimal configuration based on the specified system components.

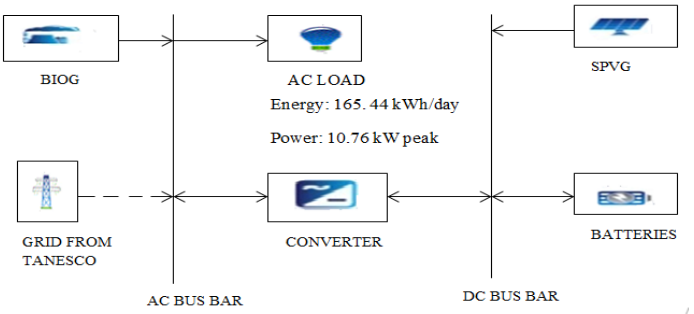


Figure 5.2. Schematic arrangement of the off-grid HRESS for the proposed site

Grid has been incorporated in the hybrid PV/biogas/battery bank storage system just for financial comparative purposes and thus does not generate any power as a result.

5. 3.2. Area of Study, System Design and Energy Analysis

Simboya village is one of two communities constituting the Ikukwa ward in Mbeya rural district of Tanzania'. Simboya village is geographically limited by Mount Mbeya, the Chunya district in the Mbeya area, and the Songwe region. Figure.5.3. indicates map of location of Simboya village at Ikukwa ward in Mbeya region, Tanzania. This village is affected by a lack of access to power as a result of the national grid extension. Table.5.1 shows summarized profile for Simboya village.

Table 5.1**:** Summarized profile of the Simboya village (Authors' Survey, 2019)

Particulars	Description	Remarks
Name of the village	**Simboya**	Under VEO
Date of establishment	1998	Formed after Subdivision of the former Ikukwa village established in 1964
Number of sub-villages	09	Records from ward agricultural office
Number of residences	483	Records from ward agricultural office
Number of rivers	01	The river Shongo
Total area	5522 m^2	Data by Ikukwa ward office (WEO)
Total area for residences	3622 m^2	Data by Ikukwa ward office (WEO)
Agricultural area	700 m^2	Data by Ikukwa ward office (WEO)
Pastoralist area	1200 m^2	Data by Ikukwa ward office (WEO)
Total population	2536	Number of males 1236 Number of females 1300
Electricity availability	00	---
Ward name	Ikukwa	---
Name of a district	Mbeya rural	---
Name of a region	Mbeya	---
Latitude	8° 54.6´ S,	---
Longitude	33°27.6´E	---
Country	United Republic of Tanzania	---

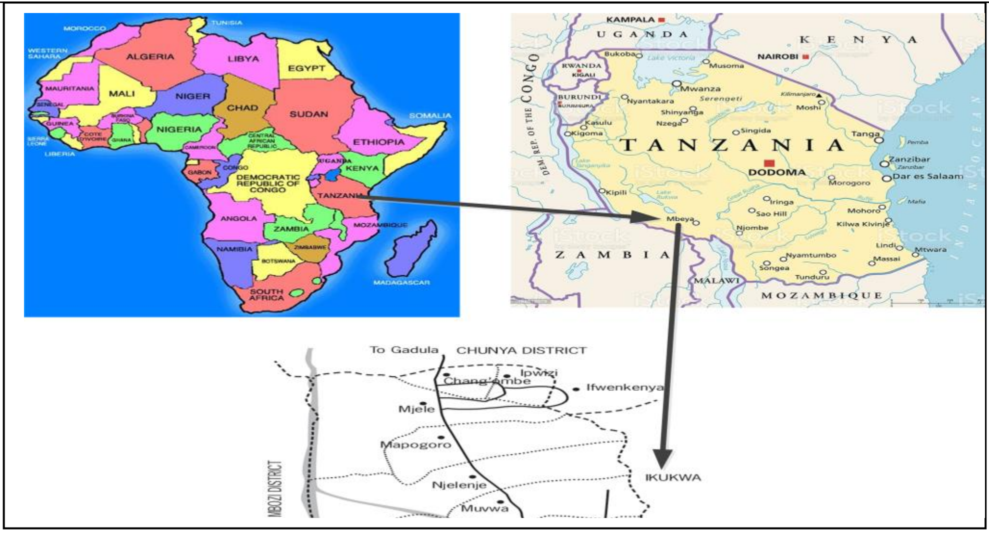


Figure 5.3. Map of location of Simboya village at Ikukwa ward in Mbeya, Tanzania

5. 3.3 Design of the System and Energy Analysis

5. 3.3.1 Solar energy resource

The NASA (National Aeronautics and Space Administration) and (SSE) Surface Meteorology and Solar Energy provided monthly solar radiation and wind energy statistics (Mwakitalima *et al*., 2021). The scaled annual average solar irradiance is 6.11 kWh/m^2/day at proposed the site. Table1 shows clearness index and Monthly Solar Radiation data and wind speeds at height of 10 m**.** Figure 5.4 indicates the monthly solar radiation and clearness index at the proposed site.

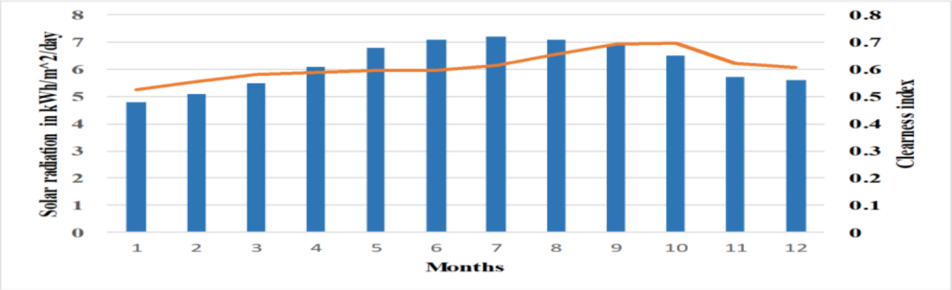


Figure 5.4. Synthesized monthly solar radiation and clearness index at the proposed site

5. 3.3. 2 Biomass energy resource

Following is the chemistry for producing biogas fuel during anaerobic digestion process: (Patel and Singal, 2018)

$$\{C_6 + H_{12} O_6 \rightarrow 3CO_2 + 3CH_4, CO_2 + 4H_2 > CH_4 + 2H_2O, CH_3COOH > CH_4 + CO_2\} \qquad (5.1)$$

The fuel is made up of two main components: methane (CH 4) and carbon dioxide (CO 2), which account for around 55-65 percent and (35-45 percent) of the total. It also contains minute amounts of sulphide and a gaseous form of water (Curry and Pillay, 2012). The simplified process of converting of biomass obtained from animal and poultry wastes into biogas fuel for generation of electricity is portrayed in Figure 5 .5.

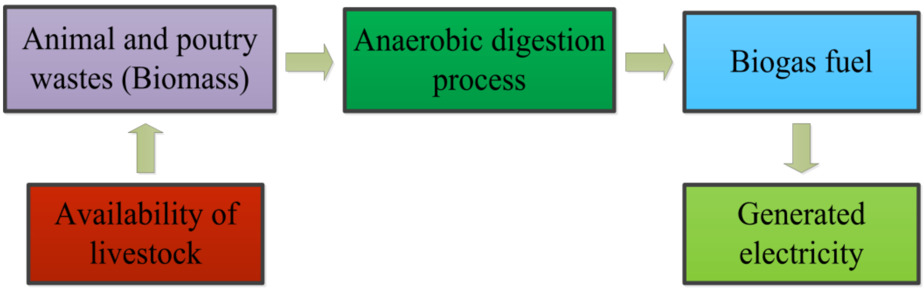


Figure 5.5. Simplified stages of electricity generation from biogas fuel (Source: Author)

The purpose of this research is to assess the potential for animal faeces and poultry droppings in the hamlet. Data collection for animal identification and quantification was done through consultation with ward leaders, consultation with individual villagers, and records in the crops and livestock office library in Ikukwa ward. Table 5.2 shows a list of livestock at Simboya village in Mbeya rural district.

Table 5.2: List of livestock at Simboya village in Mbeya Rural District

Livestock	Cattle	Goats	Donkeys	Sheep	Pigs	poultry
Total number	873	602	82	31	86	1448

The amount of dung produced per cattle each day varies according to numerous criteria such as body size, kind of feeding, and amount of nutrition. For simplicity, production rates are estimated based on the number of surveyed herds in Simboya community, Mbeya rural district, Tanzania. Table 5.3 below indicates yield of dung per head per day for Simboya village at Ikukwa Ward in Mbeya Rural District.

Table 5.3: Assumed yield of dung per head per day for Simboya village at Ikukwa Ward in Mbeya Rural District

Livestock	Assumed animal dung (kg/head/day)	Number of animals	Total dung (wet) (kg//day)
Cattle	10	873	8730
Goats	1	602	602
Donkeys	8	82	656
Sheep	1	31	31
pigs	2.35	86	202.1
Poultry	0.10	1448	144.8
		Total	10, 365.9

The aggregate amount of animal and poultry droppings dung produced each day is 10,365.9 kg. To begin, the animal waste collection efficiency is considered to be 60%. Thus, the total gathered per day is 60% multiplied by 10, 491.8 kg/day is 6, 295.08 kg/day. This amount is adequate to generate biogas for the village households' electricity and cooking. Out of the total daily biomass, an average of 2040 kg/day has been used for biogas energy generation. The average cost of biomass, LHV (low heating value), carbon content, and gasification ratio are respectively 3.0 $/ton, 5.5 MJ/kg, 5.0 percent, and 0.7 respectively. Second, it has been noted that the bulk of livestock and poultry in Africa move from one location to another in search of pastures. The harvesting of biomass for biogas generation may be difficult. In this study, zero grazing is anticipated for effective collecting of animal waste and poultry droppings. Third, it is assumed that the grass is the primary source of food for the animals. The presence of grass is typically influenced by the weather of the particular location. It is now possible to conclude that the amount of biomass harvested during wet seasons is greater than that collected during dry seasons.

In other words, the faster the rate of feeding the animals, the greater the amount of biomass produced per animal head. Based on these assumptions, the annualized monthly average produced from biomass resource is dispersed over a one-year period. The highest and lowest annual monthly average biomass resources are produced in January (0.787 tonnes/day, equivalent to 12.5% of total trash) and from July to October (0. 315 tonnes/day, corresponding to 5% of total waste), respectively. From March through April, daily recoverable biomass is predicted to be 0. 692 tonnes or 11% of total available biomass. In addition, the daily average weights of the acquired biomass in November and December are 0. 378 tonnes (6 percent) and 0.598 tonnes, respectively.

Figure 5.6 indicates annual monthly average available biomass resource for backup electricity generation. Daily generated power is given in the following equation (Rajanna and Saini, 2016):

$$P_{BIOG} = \frac{Q_{BIOG} \times CV_{BIOG} \times \eta_{BIOG}}{(T_{OPD} \times 860)} \tag{5.2}$$

Where, Q_{BIOG} denotes amount of biogas (m ^{3}/day), P_{BIOG} is power generated by biogas power plant (BPP) in kW, CV_{BIOG} is calorific value of biogas fuel (4700 kcal/ m^3), η_{BIOG} is overall efficiency of BPP, T_{OPD} is operating time per day in hours (Rajanna and Saini 2016). The remainder of daily biomass resource equals to 4, 255.08 kg/day. In this study, 1 kg of dung is assumed to produce daily amount of biogas of 0.036 m^3 (Rajanna and Saini, 2016). As a result, total biogas production for cooking for all households in the village equals to 0.036 m^3/kg times 4, 255.08 kg/day is estimated to be 153.2 m^3/day. The village comprises of 483 families with small amount of biogas for cooking per household which is equivalent to 0.32 m^3.

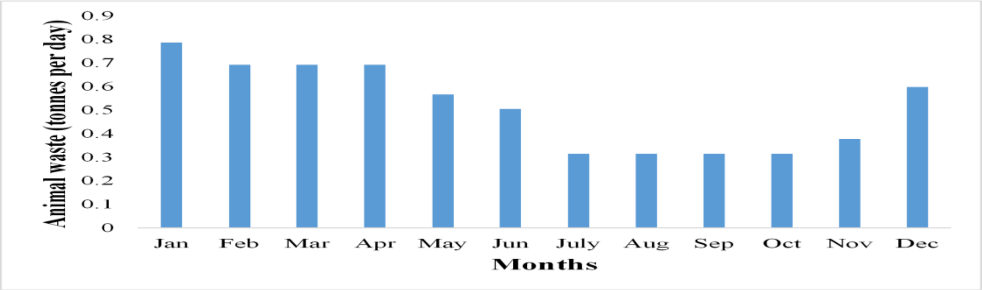


Figure 5.6. Annual monthly average available biomass resource

5. 3.3.3 Electrical load demand classification

The estimated load demand was derived from information gathered from residents and field surveys conducted in various portions of the hamlet. These surveys are divided into several categories, including street lighting, residential, institutional, commercial, small-scale industrial, irrigation, and agricultural loads. Data was gathered from the estimated rated power of appliances based on the type of electrical services. The lighting load is present in all parts. Residential loads include illumination, a television, a radio, a DVD player, a phone charger, and an electric iron. Schools (primary and secondary), religious institutions, and community centres are examples of institutional loads. The equipment of Mbeya District Council Hospital (MDCH), commonly known as Ikukwa Health Centre (IHC), is also included in this specific study.

The estimated load demand was derived from information gathered from residents and field surveys conducted in various portions of the hamlet. These surveys are divided into several categories, including residential, institutional, commercial, street lighting, small-scale industrial, irrigation, and agricultural loads. Data was gathered from the estimated power rating of appliances based on the type of electrical services. The lighting load is present in all parts. Residential loads include illumination, a television, a radio, a DVD player, a phone charger, and an electric iron. Schools (primary and secondary), religious institutions, and community centres are examples of institutional loads. All equipment of MDCH is included. Morgue, laundry, image (X-ray & CT scan), administration building, theatre, maternity, premature babies' services, clinic block, laboratory, minor surgery, pharmacy and store, injection room, dental room, staff households, security and street lighting, and miscellaneous sections use hospital equipment. Commercial loads include small-scale stores, grocery, male and female saloons. Sewing machines, small carpentry workshops, milling machines, and welding machines are examples of small-scale industrial loads. The majority of the street lighting burden is made up of security lights. Deferred load has been overlooked because irrigation and agriculture do not require water pumping equipment, whereas electric power is required for transportation. The electrical load profile must be carefully considered for the proposed off-grid HRESS to work effectively. Any type of periodic load variation might cause major system reliability issues. Due to the low load factor in rural areas, acquired data from the surveys were purposefully distributed over a 24-hour cycle on the excel data sheet based on the energy demand of each part. The engineering judgment mirrored to time, social behaviour, and the nature of economic activity in the given area of research was used to distribute each load category. The daily load profiles derived from the excel data sheet for the entire hamlet were validated using the HOMER platform. Table 5.4 displays the electrical load categories in consideration of the consumer at Simboya village.

Table 5.4: Electrical load categories in consideration of consumers at Simboya village

Load classification	Wattage in watts collected from rating of electric appliances
Residential	465945
Institutional load including Ikukwa health centre	190730
Commercial	18 121
Small-scale industrial	265 338
Street lighting	4800
Irrigation and agricultural	0
Transport	0
Total	944934

Because the country is located in a tropical zone, the seasonal change of load based on winter and summer is not considered because there is no variation in temperatures between the two seasons and thus no requirement for space heating/cooling equipment (Syahputra and Soesanti, 2020).

(a) Estimation of electrical load demand at pre-HOMER level using excel program

The appraisal is done in the Microsoft succeed worksheet by modifying information layouts before the point by point assessment by HOMER star programming (Nimma *et al.*, 2018). Figure 5.7 shows electrical burden in light of the thought about applications for the area of study. Nature of diagrams of force utilization is essentially founded on the way of behaving of financial exercises of individuals abiding in the space of study. The heap order above is additionally sorted according to thought of the awareness of wellbeing conveniences. Here the awareness means to guarantee the consistent accessibility and dependability to the sound office. The town power utilization is sorted into two principle gatherings, for example, load profile 1 and burden profile 2 (Nimma *et al.*, 2018). In this review, load for IHC is barred from institutional burden and is joined with road lighting. For productive and viable of the wellbeing community road lighting is fundamental significance. Along these lines, load profile 1(critical load) incorporates electrical load for the IHC and road lighting. Electrical burden for IHC is established by the implementation of hardware of various paces of force utilization. In this particular, concentrate because of the awareness of IHC its power utilization has been thought to be steady over the course of the day. Private burden is assessed to be 30 kW addressing half of day to day greatest pinnacle interest. Lighting load is the most reduced around 0.2 kW while power for transport and inundated farming is zero. Load profile 2 (Non-basic load) comprises of private, business, institutional loads and Small-scale modern burdens [(Nimma *et al*., 2018). Provincial zap projects in light of business and limited scope modern burdens are restricted useful purposes in the country. Figure 5.8 shows basic burdens which incorporate the energy interest for MDCH office (otherwise called IHC) and road lighting load.

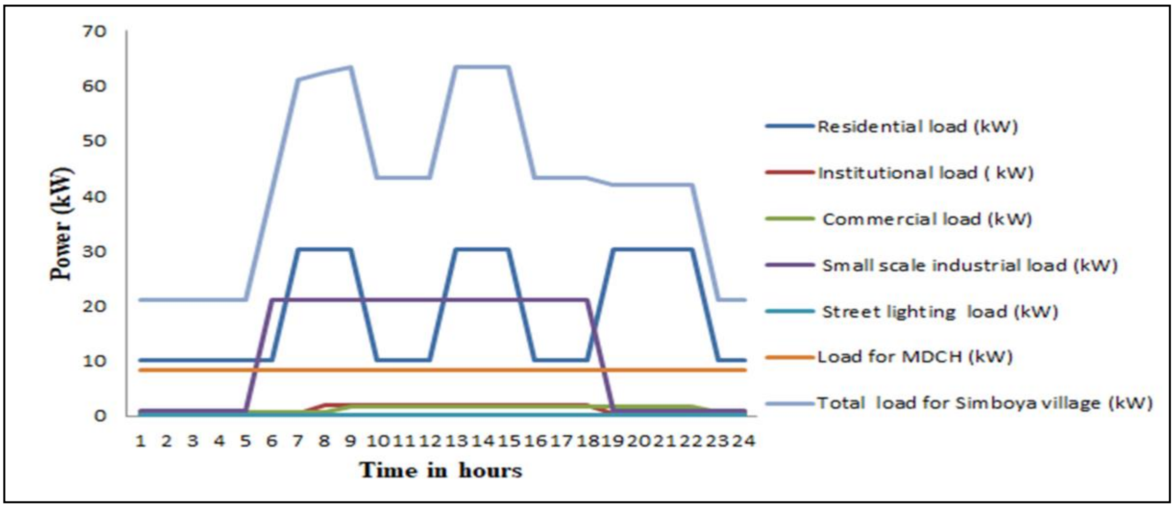


Figure 5.7. Accumulated load profile of various applications in the area of study

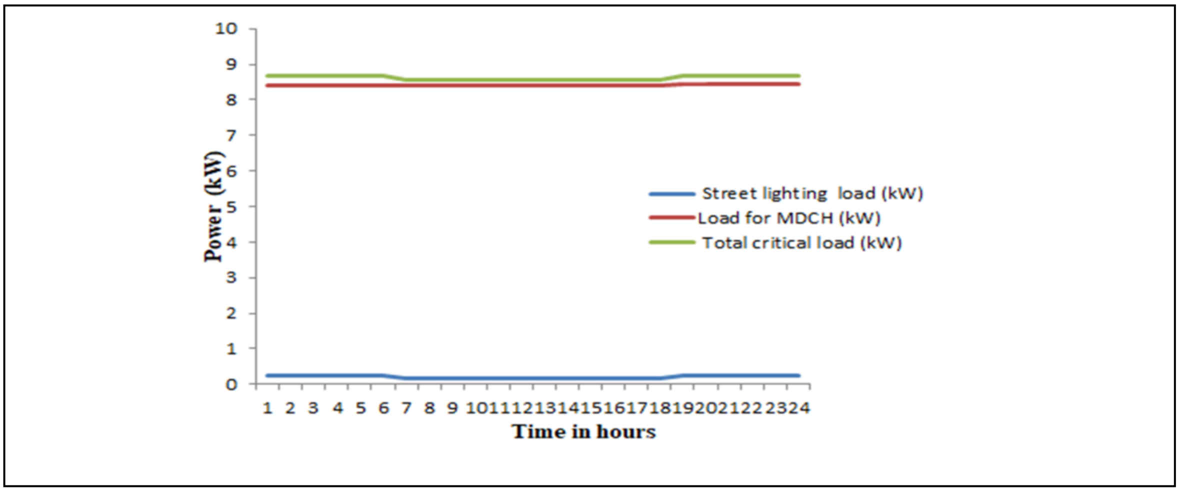


Figure 5.8. Critical load combining MCDH (IHC) and street lighting loads

(b) Comprehensive electrical load demand analysis using HOMER

The load profile estimation in an excel data sheet is practically limited to highest power capacity. It is unable to provide daily energy usage, power fluctuation, or load factor. As a result, electrical load demand is partially validated in HOMER pro software based on the current categories of consumers in the village in order to discover the lowest cost amalgamation of supply choices by satisfying demand (Nimma., 2018). As previously stated in this study, the HRESS is predicted to generate electricity for the village (community) with a daily load of 165.44 kWh and a peak output of 10.76 kW peak (scaled) or 63.41 kW baselines with a load factor of 0.64. Figure 5.2 shows schematic diagram for the HRESS for the proposed site. The considered HRESS is 100 % renewable meaning that no DG has been employed. Table 5.5 gives summary of electrical power consumption for Simboya village per AC load classification processed in HOMER pro software. In this study, the daily load profile for IHC and its surrounding street lighting has been assumed to be constant all the time though there is variation of power consumption. Figure 5.9 indicates daily power for non-critical load (consisting of residential, institutional, commercial, and small scale-industrial loads).

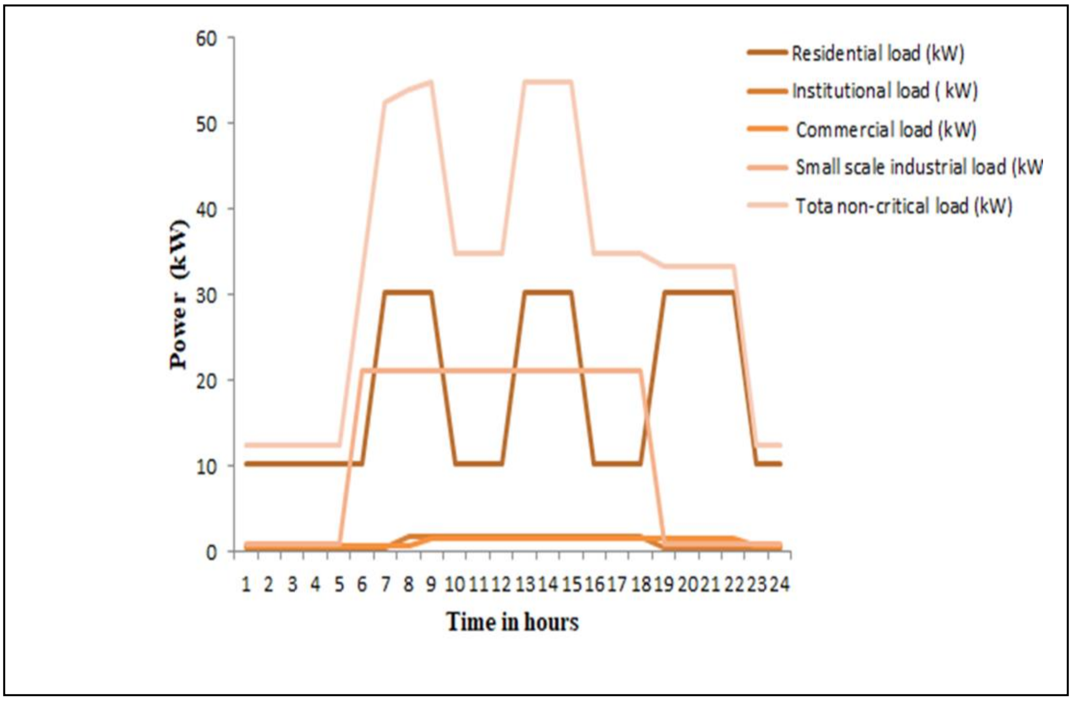


Figure 5.9. Daily power for non-critical load (consisting of residential, institutional, commercial, and small scale-industrial loads)

Table 5.5: Summary of electrical power consumption for Simboya village per AC load classification processed in HOMER pro software

Village load classification	Baseline max. power (kW)	Scaled consumption (kWh/day)	Scaled max. power (kW)	Load factor
Residential load	30.27	11.26	0.76	0.61
Institutional load	3.18	165.44	18.45	0.37
Commercial load	2.69	165.44	15.84	0.44
Small-scale industrial load	35.81	165.44	22.33	0.31
Ikukwa health centre (IHC)	8.42	165.44	6.89	1
Street lighting	0.42	165.44	14.94	0.46
Accumulated village load	63.41	165.44	10.76	0.64
Critical load	14.72	165.44	11.77	0.59
Non-critical load	54.84	165.44	11.82	0.58

5.4 DESCRIPTIONS OF COMPONENTS AND DESIGN OF OFF- GRID HRESS

According to the results of a survey conducted in the research area, solar and biomass energy resources have a great potential for generating power. SPV panels and Biomass/Biogas generators are thus the electricity generating components of HRESS. Biogas generator is employed as a backup in this study. Deep cycle batteries and converters, for example, are also incorporated in the system for energy storage and electrical power conversion respectively.

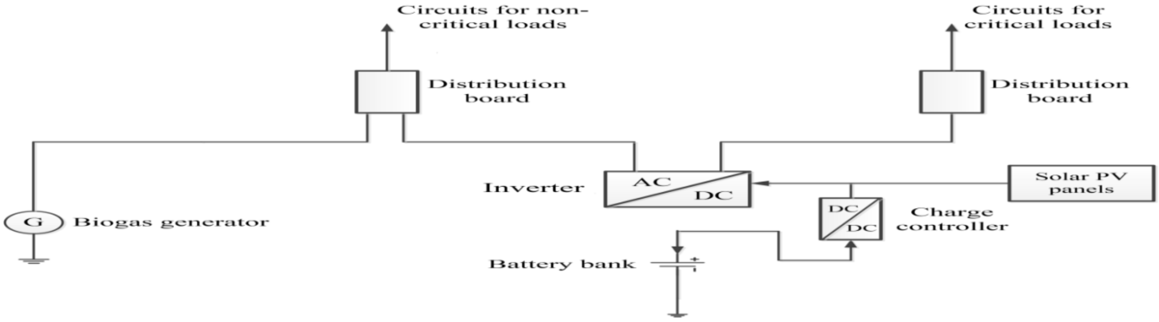


Figure 5.10. Schematic of the proposed off- grid hybrid solar PV-biogas-battery system (Source: Author)

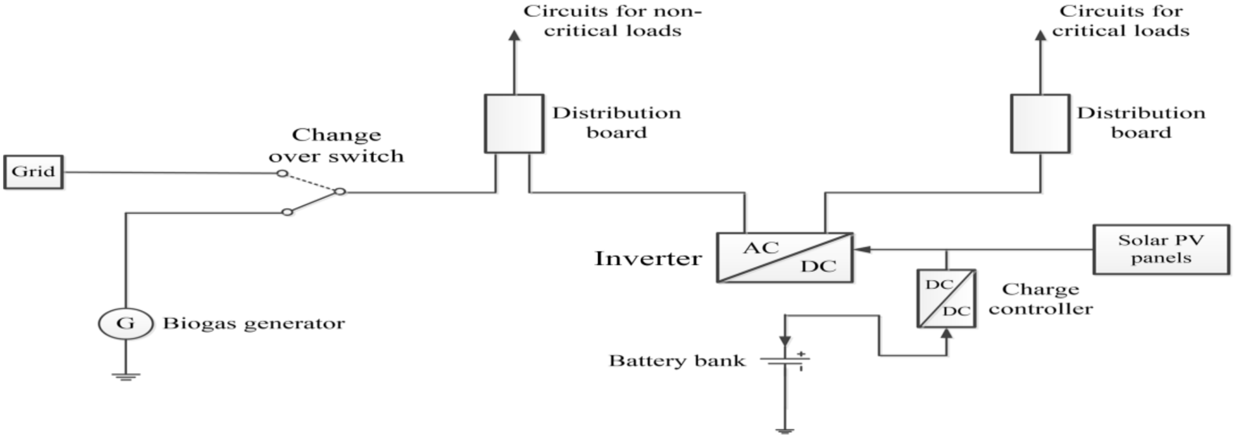


Figure 5.11. Schematic of grid- connected hybrid solar PV-biogas-battery system (Source: Author)

HOMER pro software analysis achieves optimal configuration based on these selected components. Figure 5.10 indicates wiring scheme for the proposed off-grid hybrid SPV-biogas-battery system for Simboya village and Figure 5. 11 shows wiring scheme for grid connected hybrid solar PV-biogas-battery system for Simboya village.

However, in this study, grid connectivity of a grid-connected hybrid SPV-biogas-battery system was only examined for economic comparison and the assessment of the Economic Distance Limit (EDL) for practical grid expansion. The dependability and cost-effectiveness of components are critical factors in the design of a successful micro-power system. HRESS's component selection and design are as follows:

5.4. 1 Selection of Components

An SPV system is made up of several panels connected in series. SPV power output is a key power source in HRESS due to its cost-effectiveness when compared to BIOG of equal capacity. SPV has been built to produce 40 kW of power. The monetary input variables have been specified in the system optimization. The original cost and replacement price for a 1 kW PV system are $ 700.00 and $ 0 correspondingly. S PV performance is estimated to be adequate within the timeframe of the project's anticipated life span of 25 years.

SPV maintenance and operation (O & M) costs only $ 1.5 per year. To compensate for the ambient temperature and filthy conditions, the de-rating factor for the individual photovoltaic cells is set at 80%. There is no tracking system in the SPV system. BIOG is also designed to offer a power output of 25 kW. The original cost, replacement cost, and O&M cost for a 1 kW BIOG capacity are $ 260, $ 160, and $ 0.90/op.hr, respectively. BIOG is connected to an alternating current output and has a lifecycle of 20,000 hours. The minimum load ratio is set to 50% of the overall power capacity. A bank of deep cycle batteries was used to store extra power during periods of strong solar radiation and to distribute the stored energy to the electrical load when there was no solar energy resource available. The battery chosen is a Generic 1kWh Li-ion with a nominal voltage of 6 V. The bank is made up of 144 batteries, with four batteries connected in series per string and 36 strings connected in parallel, and the system bus voltage is 24. The initial price, replacement price, and O&M expenses per unit of battery were determined to be $700, $ 0, and $ 1.5/year, respectively. The battery bank has a 17-hour autonomy and a lifetime throughput of 432, 000 kWh. The inverter's intended rated power output is 40 kW. The original pricing, replacement fee, and O&M expenses for a 1kW converter capacity were considered to be \$ 200, \$ 200, and \$ 10 accordingly. The converter has a 15 percent life expectancy, whereas the inverter and rectifier efficiency are both 95 percent.

5.4. 2 Design of the Proposed Off-Grid HRESS

In this work, the design of optimal solar photovoltaic- biogas- battery system was implemented in HOMER pro software. Data for system configuration and selected components are used for optimization process. Parameters such as capital price, cost of energy, net present cost are obtained in the optimal design compared. Economic comparison is made in the financial section. There is a problem of uncertainty problem due to the intermittent nature of renewable energy sources (RESs).

Uncertainties are related with the variability of the key input parameters of RES and thus leading to the complicated design of micro distributed electric generating system (Ahmed, Sreeram *et al.* 2020). In this study, uncertainties have been considered and therefore variables such as solar radiation, fuel price and load variation based on assumed scenarios (100% RE scenario) which is a proposed primary scenario or base case scenario of which biogas is used as a backup, in second scenario DG is used as back-up instead of biogas and third scenario DG is assumed to deliver power to the micro- power system for continuous duty. Life Cycle Cost (LCC) method is used for financial comparison among the simulated feasible systems. The system which has the lowest NPC is the most economically favorable system, that is, optimally designed system. In this study, economics and constraints for the project are such as operating reserve is 80 %, nominal discount rate is 8 % and expected inflation is 4%. In this work, grid extension is used as a reference by HOMER for the comparison of both technical and financial parameters of the off- grid HRESS. Therefore the specific objective of economic analysis between grid extensions versus off-grid HRESS is to examine whether the grid extension is viable or not. Critical price of grid extension per kilometre for the available terrain at Simboya village is considered to \$8000/ km. The yearly O &M cost per kilometre is considered to be \$1500/year and grid power price in Tanzanian environment is assumed to \$ 0.44/ kWh. Based on LCOE and economic distance limit (EDL), comparison for the economic effectiveness between the most favorable off-grid HRESS and grid extension for rural electrification is carried out. The price for the low voltage (LV) distributions systems in the village is not inclusive because the cost is similar in both options. Environmental analysis is also carryout to investigate amount of emissions or pollutants in proportional to the selected components of proposed off-grid HRESS.

5.5 MODELLING OF AMALGAMATED POWER SYSTEM DEVICES

It should be recalled that in this study, three off- grid optimal configurations, namely, solar PV-DG- battery, solar PV- Biogas generator-battery, and DG only systems have been compared. Out of the three optimized configurations, solar PV- biogas generator-battery is the most cost effective. Modelling of the individual components of the system is as follows:

5.5.1 Solar PV generator

Solar power is generated based on the available solar energy resource at a given location. In this study effects of temperature on solar cells are ignored. Therefore, energy output of the solar PV generator can be computed using Equation (5. 3) as follows (Lal, Dash et al. 2011)

$$G_{PV}(t) = Q(t) \times A \times D \times \acute{\eta}_{PV} \tag{5.3}$$

Where, $Q(t)$ represents the solar radiation (kWh/m^2), surface area of the solar module (m^2) is denoted by A, D symbolizes the solar energy penetration factor, and $\acute{\eta}_{PV}$ denotes the efficiency of solar PV generator (%).

5.5.2 Biogas generator

In a biogas powered generator, electricity is generated from the biological wastes. Power generated by biogas is generally expressed in Equation (2). However, for the purpose of modelling this equation can alternatively be expressed as follows in Equation (5.4) *(Suman et al.*, 2021).

$$P_{BIOG} = \eta_{BIOG} \times U_P(t) \times CV_{BIOG} \tag{5.4}$$

Where, U_P(t) is the amount of biogas consumed (m ^{3}/h), CV_{BIOG} refers to the efficiency of the system (Assuming is equal to 27 %), and CV_{BIOG} embodies the LHV (kWh/m^3). LHV relies on the concentration of CH_4 of the biogas. LHV is assumed to be 21. 78 KJ/ m ^{3} assuming concentration of CH_4 is equal to 60 %.

5.5.3 Battery bank

In case energy generated by biogas and solar photovoltaic generators cannot satisfy the electrical load demand, battery can start discharging in order to overcome such an imbalance.

The battery capacity depends on SOC. Battery capacity of the system is defined in Equation (5) as follows (Hermann *et al.* 2022):

$$G_{btt\,(t)} = \frac{E \times DA}{V_{btt} \times DOD \times \eta_{btt}} \tag{5.5}$$

where, E denotes the daily energy demand (Wh), DA represents the number of days of battery bank autonomy, V_{btt} delineates system voltage, depth of discharge is abbreviated as DOD, and η_{btt} stands for the battery efficiency. Quantity of batteries is prescribed based on ampere hour capacity.

5.5.4 Converter

Converter is a bidirectional device combining inverter and rectifier to maintain the direction of an electric current between the alternating current (AC) and direct current (DC) appliances. This device is necessary for smoothly interfacing energy sources, electrical load and energy storage systems. Electrical load and biogas generator are connected to AC bus bar while solar photovoltaic array and battery bank system are connected to DC bus bar. Converter power capacity should be at least greater than the highest load demand in order to permit greatest rated power flow. Generally, input power to inverter is computed using equation (5.6) as follows (Hermann *et al.*, 2022):

$$E_{INV} = \frac{E_L}{\eta_{INV}} \tag{5.6}$$

Where, E_{INV} and η_{INV} defines the input power and the efficiency of inverter respectively.

5.6 ECONOMIC AND TECHNICAL INPUT DATA OF THE PROPOSED OFF-GRID HRESS

This section describes the financial and technical specifications including the details site of the project. In particular, the section presents the financial and technical specifications of selected solar panel, biogas generator, battery, converter and description of site of the project. Input parameters for solar panel, biogas generator, and converter respectively.

5.6.1 Input Parameters of SPV Generator

In this study, solar PV power system is considered to be fixed mounted. The system is made by connection of a number of solar panels so as to achieve required values of system voltage and current flow. One type of PV panel is selected from Saatvik Green Energy Company with presumed costs for Tanzanian environment (Saatvik, 2022). Table 5.6 provides the input parameters of solar PV module.

Table 5. 6: Input parameters of solar PV module

Parameter	Specifications
Manufacturer	Saatvik Green Energy Company
Model	SGE 335-72M
Rated power	335 Wp
Technology	Polycrystalline
Dimensions	1955mm × 991mm× 35mm
Short circuit current, $\boldsymbol{I_{SC}}$	9.35 A
Open circuit voltage, $\boldsymbol{V_{OC}}$	46.25 V
Efficiency	17.29 %
Capital cost	$ 700
Operation and maintenance cost	$ 1.5/ Year
Replacement cost	$ 0
Lifespan	25

5.6.2 Input Parameters for Biogas Generator

The highest power to be produced by the biogas generator is anticipated to be 25 kW. Therefore, based on this fact, a unit of biogas generator from NPT General Exporters is considered and all costs of the unit are adapted for Tanzania environment (Exporters in India, 2022). Table 5.7 shows input parameters of the selected biogas generator.

Table 5.7: Input parameters of biogas generator

Parameter	Specifications
Company	NPT General Exporters
Model	KDGH25- G
Rated voltage	25 kW
Rated voltage	400V/415V/380 V
Frequency	50 HZ
Number of phase	Three phase (AC)
Power factor (Lagging)	0.8
Engine model	HG4B
Speed	1500 RPM
Type of cooling	Natural cooling
Provision of power	Continuous
Capital cost	$ 260
Operation and maintenance cost	$ 0.9 / Year
Replacement cost	$ 160
Lifespan	35

5.6.3 Input Parameters of Battery

Intermittency nature is one of the drawbacks of renewable energy sources thus necessitate the use of energy storage systems like batteries. One type of battery is chosen from Shenzhen

GSL Energy Company with presumed costs for Tanzanian environment (Shenzhen energy Ltd, 2022). Table 5.8 provides the input parameters of battery.

Table 5. 8: Input parameters of battery

Parameter	Specifications
Manufacturer	Shenzhen GSL Energy Company
Model	KS-12300
Nominal voltage	12 v
Nominal capacity	300 AH
Type	Lithium Ion battery (Lifepo4 Battery)
Cycle life	More than 3000 times
Efficiency η_{btt} , (assumed)	85
DOD (assumed)	80
Lowest permissible charge	20
Capital cost	$ 700
Operation and maintenance cost	$ 10 / Year
Replacement cost	$ 700
Lifespan	10

5.6.4 Converter

In this particular study, the capacity of the converter is assumed to be 20 % higher than the estimated highest daily load demand. Converter experiences switching and conduction power losses (Semeskandeh *et al.,* 2022). Arithmetically, E_{INV} can be simply determined using equation (5.7) as follows:

$$E_{INV} = E_L + (\,20\,\%\ of\ E_L\,) \qquad (5.7)$$

If E_L equals to 63.41 kW is substituted into Equation 7 therefore estimated E_{INV} equals to 76.092 kW. According to the available market, inverter capacity of 80 kW is selected from Novergy Energy Solar Pvt Ltd (Novergy, 2022). Table 5.9 provides the input parameters of converter.

Table 5.9: Input parameters of converter

Parameter	Specifications
Manufacturer	Novergy Energy Solar Pvt Ltd
Model	IPCL 80 kW
Type	Hybrid (ON GRID / OFF GRID)
Rated output voltage	380v/ 400 v/415 v AC ,TPN
Rated power capacity	50 HZ
Rated power capacity	80 kW
Power factor	0.8 lagging
Efficiency η_{INV}	92 %
Capital cost	$ 200
Operation and maintenance cost	$ 10 / Year
Replacement cost	$ 200
Lifespan	10 years

5.6.5 Description of Connected Electrical Load

Electrical load is one or more appliances which are deliberately connected to electric system to utilize electrical energy. For a proper design of any energy system for a given place, it is noteworthy to carefully consider the electrical load profile. Periodic variations of the electrical load needs to be known for achieving high reliability system by maximization and minimization of power resources and costs respectively. Moreover, capacities of energy storage systems and energy sources rely on the electrical load profile. The data of load variation for the site under study are equal to 165.44 kWh/ day and 63.41 kW.

5.6.6 Description of the Site of the Project

This section provides the information related with the site such as lifespan, nominal discount rate and inflation rate. Table 5.10 indicates the assumptions of input parameters of the site.

Table 5.10: Assumptions of input parameters of the site

Parameters of the project	Specifications
Lifespan	25 years
Nominal discount rate	8%
Expected inflation rate	4%

5.7 STRATEGY FOR MANAGING OFF-GRID HRESS

Solar PV and biogas generator are the main sources constituting the hybrid energy system. Batteries are also incorporated in the system in order to compensate the incompatibility between the energy demand and generated power.

Power generated by solar panels can be defined using equation (5.8) as follows (Hadidian-Moghaddam *et al.*, 2016) :

$$G_{PV}(t) = n_{PV} \times p_{PV}(\mathrm{t}) \tag{5.8}$$

where, $G_{SP}(t)$ represents total power produced by solar photovoltaic array, n_{PV} refers the quantity of solar panels, and $p_{PV}(\mathrm{t})$ denotes power produced by one solar photovoltaic panel.

Similarly, power generated by biogas generator can be defined using Equation (9) as follows (Hadidian-Moghaddam *et al.*, 2016):

$$G_{BIOG}(t) = n_{BIOG} \times P_{BIOG}(\mathrm{t}) \tag{5.9}$$

where, $G_{BIOG}(t)$ represents the total power produced by all biogas power generating units, n_{BIOG} refers to the quantity of biogas generators, and $p_{BIOG}(\mathrm{t})$ indicates power produced by a single biogas generator.

Total generated power obtained by the two sources is expressed by a combination of Equations (8) and (9) as follows (Hadidian-Moghaddam *et al.*, 2016):

$$G_{SB}(t) = G_{PV}(t) + G_{BIOG}(t) \qquad (5.\ 10)$$

Alternately, Equation (5.10) may be re-written using Equation (5.11) as follows:

$$G_{SB}(t) = n_{PV} \times p_{PV}(\mathrm{t}) + n_{BIOG} \times \ p_{BIOG}(\mathrm{t}) \qquad (5.11)$$

The produced power from the two renewable energy sources based on their obtainability is computed as follows (Hadidian-Moghaddam *et al.*, 2016):

$$G_{SB}(t) = n_{PV} \times \ p_{pv} \ \times A_{pv} + n_{BIOG} \times \ p_{BIOG}(\mathrm{t}) \qquad (5.\ 12)$$

Management strategy of renewable energy systems is complicated due to the discontinuous nature. In this study, the strategy consists of several setups are explained as follows:

(i) Setup 1: Battery bank is allowed to charge only if electrical load is met by all energy sources

The battery bank is allowed to charge when power generated by energy system is greater than the energy demand at given time. The battery bank is charged to store the surplus energy when load is satisfied first. Energy stored by the battery bank is expressed in Equation (5.13) as follows (Sansa *et al.*, 2015):

$$G_{btt\,(t)} \ = \ G_{btt\,(t-1)} + (G_{SB\,(t)} - \frac{E_L\,(t)}{\eta_{ivt}})* \eta_{btt} \qquad (5.13)$$

Where, $G_{btt\,(t)}$ and $G_{btt\,(t-1)}$ are defined as electrical energies stored in the battery bank at t and $t-1$ times respectively,$G_{SB\,(t)}$ represents energy produced by the hybridized energy system, η_{btt} and η_{ivt} represent efficiencies for battery and inverter respectively, and energy demand at time t is symbolized by$E_L(t)$.

(ii) Setup 2: Battery discharges only if electrical load is not met by all energy sources

The battery bank is required to discharge if power generated by the energy system is lower than the energy demand at given time t. Therefore, the energy from battery bank is discharged to meet the load. Energy discharged by the battery bank is described in Equation (14) as follows (Sansa *et al.,* 2015):

$$G_{btt\,(t)} \;=\; G_{btt\,(t-1)} - (\frac{E_L\,(t)}{\eta_{ivt}}) - G_{SB\,(t)}\,) \tag{5. 14}$$

(iii) Setup 3: Otherwise the load is not met by energy sources and battery storage system meaning that there is deficiency of energy. This idea will fully discuss in relation with system reliability (Sansa *et al*., 2015).

5.8 OPTIMIZATION OF OFF-GRID HRESS USING GWO METHOD

In the first phase of this paper, has been executed in HOMER pro software. This software provides the mimics the probable system configurations to acquire the optimal arrangement of hybridized energy sources to meet the daily load demand. Input data related to solar radiation, biomass particularly animal and poultry wastes, components of the system and load demand have been used for the simulation process. In the second phase, application GWO method is employed. In this particular phase, LEPP, NPC and COE are minimized. These parameters are known as objective functions. Decision variables are rated power output of Solar PV, number of biogas generator, Autonomy days of battery system, and number of DG. In short, this section deals with of financial and technical optimization models as follows:

5.8. 1 Technical Optimization Model

This section of the paper offers the detailed explanation of reliability of the system in relation with the setup 3 of management strategy. LEPP defines reliability factor of a micro-grid system. Reliable energy system can meet the load sufficiently for a given period of time. On the other hand, the less the LEPP the more the system is reliable. LEPP denotes a reliability factor of micro-grid system. If the value of LEPP is equal to zero it means that power generated and load demand are perfectly balanced. If the same factor is equal to one it implies that there is an imbalance of power generated and load demand due to the shortage of electricity. Therefore, before defining LEPP mathematically, the deficiency of electricity called unavailability of electricity Supply (UES) is expressed in Equation (5.15) as follows (Sansa *et al*., 2015):

$$UES_{(t)} = \; E_{L(t)} - (G_{PV}(t) + P_{BIOG}(t) + G_{btt\,(t-1)} - G_{bttMIN}) * \;\eta_{ivt} \tag{5.15}$$

Now LEPP for duration of time T can be defined as a ratio of the whole UES calculated every period t to the sum of power demand. The ratio is mathematically described in equation (5.16) as follows (Sansa *et al.*, 2015):

$$LEPP = \frac{\sum_{t=1}^{T} UES_{(t)}}{\sum_{t=1}^{T} E_{L(t)}} \tag{5.16}$$

Renewable fraction (RF) is defined as a fraction of power delivered to the load which is generated by non-conventional energy sources. Numerically, REF is expressed using equation (5.17) as follows (Hermann *et al.*, 2022):

$$RF = 1 - \frac{\sum_{t=1}^{8760} out_{DG(t)}}{\sum_{t=1}^{8760} G_{SB}(t)} \tag{5.17}$$

$out_{DG(t)}$, connotes the power generated by conventional energy sources (solar PV and biogas). In this study, system consists of 100% non-conventional energy sources and thus RF equals to 1.

5.8.2 Financial Optimization Model

It should be recalled that in the first part of this study, HOMER platform has been used to simulate the system. The central function of the tool is to obtain optimal configuration at smallest total NPC (Chang *et al.,* 2021). This platform of research calculates the mean annualized price of each system component plus associated penalties of ecological pollutions (Chang *et al.*, 2021). This type of price is useful for determining the total NPC and LCOE (Chang *et al.,* 2021) [71]. In the second phase of this study, optimization is implemented by using AI approach using GWO method and particular economic index used is the least total NPC. Following is the description of the economic index:

5.8.2.1 Computation of total NPC

The NPC can be simply defined as a sum of whole expenses of project's lifespan in Equation (5.18) (Mudgal et al., 2019):

$$NPC = \frac{AAP}{CRF\,(i,\ J_{proj})} \tag{5.18}$$

Where, Jproj is the life span of the project in years and CRF represents capital recovery factor in Equation (5.19) (Chang et al., 2021; Mudgal *et al.,* 2019):

$$CRF\ (\ i,\ J_{proj}) = \frac{i(\ 1+i)^{J_{proj}}}{(1+i)^{J_{proj}-1)}} \tag{5.19}$$

where, CRF is defined as capital recovery factor, i is nominal discount rate and J is the life span of proposed HRESS with battery energy storage.

5.8.2. 2 Computation of aggregated annualized price

Aggregated annualized price (AAP) includes the whole annualized prices of the system in \$/year. It consists of annualized investment price (AIP), annualized spare price (ASP), and annualized fuel price (AFP) of energy source, annualized operation and repair price (AOMP) of the hybrid system. AAP can be determined using Equation (5.20) as follows (Lal *et al*., 2011):

$$AAP\ =\ AIC\ (PV + BIOG\ + BATTERY\ + CONVERTER) + ASP\ (PV + BIOG\ + BATTERY\ + CONVERTER)\ + \text{AFP}\ (PV\ + BIOG) + AOMP\ (\ PV + BIOG\ + BATTERY\ + CONVERTER) \tag{5.20}$$

AFP of solar energy source is ignores because the fuel is free of charge while that of BIOG is taken into account as biogas fuel is sold at 80 % of diesel fuel cost. In addition, for simplified analysis of the system salvage value is neglected.

5.8.2. 3 Computation of LCOE

LCOE (\$/ kWh) refers to the average charge per unit of useful generated electricity. LCOE can be computed as in the equation (5.21) as follows (Chang *et al*., 2021; Mudgal, Reddy *et al.* 2019):

$$LCOE = \frac{NPC \times CRF}{Energy\ produced\ per\ annum\ (kWh/Year)} \tag{5. 21}$$

Where, EL is the total annual energy consumption (kWh/year). LCOE may alternatively be computed in terms of AAP using equation (5.22) as follows (Chang *et al*., 2021; Mudgal *et al.*'2019):

$$LCOE = \frac{AAP\ (\$/Year)}{Energy\ produced\ per\ annum(kWh\ /Year)} \tag{5. 22}$$

5. 8.2.4 Formulating objective function and constraints

One objective optimization technique with a focus on the total NPC standards and its corresponding LCOE is employed. Research platform deployed in the entire optimization process for coding is MATLAB. The principal goal is the minimization of the total NPC. Here, total NPC represents the suitability function subject to several limits (constraints). The decision parameters are such as area of solar PV module (A_{PV}), Power generated by biogas generator (P_{BIOG}), quantity of batteries (N_{btt}), and quantity of converters (N_{CONV}). The objective function is formulated under the constraints of decision parameters and system reliability is presented in equation (5.23) as follows (Lal *et al.*, 2011):

- Objective function

Minimization of total $NPC = \sum_{i = A_{PV}, P_{BIOG}, N_{btt}, N_{CONV}} (\frac{APP_i}{CRF})$ (5.23)

- Constraints

$0 \leq A_{PV} \leq A_{PV}^{mx}, 0 \leq p_{BIOG} \leq P_{BIOG}^{mx}, 0 \leq N_{btt} \leq N_{btt}^{mx}, 0 \leq N_{CONV} \leq N_{CONV}^{mx}$, and

$0 \leq LEPP \leq LEPP^{mx}$.

Where N_{btt} and N_{CONV} are integers, A_{PV}^{mx}, P_{BIOG}^{mx}, N_{btt}^{mx}, N_{CONV}^{mx} and $LEPP^{mx}$ are greatest values of total area of solar modules, generated power by biogas power generating unit, quantity of batteries, quantity of converter, and system reliability index respectively. In this phase of study, GWO method is used to evaluate the objective function under the specified constraints. Based on the selected sizes of components of the system within their defined constrained limits, the viable configurations are found at the least total NPC in the light of the prescribed values of LEPP of the HRESS.

5. 8.2.5 Application of GWO method

GWO method was devised by Mirjalili and his co-researchers in 2014) (Suman *et al.*, 2021; Bilal and Rizwan, 2021). In accordance with the researchers, this method is motivated by the social headship pyramid and mechanism of hunting of grey wolves in nature. The commanding chain of the wolves is split up into four groups such as alpha (α), beta (β), delta (δ), and omega (ω) without taking into account the gender. In GWO method, the finest solutions are denoted by the α, followed by the β and the δ wolves (Suman *et al.*, 2021; Bilal and Rizwan, 2021). The ω is the final group (scapegoats) which is submissive to the dominant groups (.α, β and δ). The whole process of hunting is assumed to be executed by the dominant groups. The procedure of hunting is implemented in three phases such as tracing which involves chasing and moving near the target, following the victim and attacking the victim. (Bilal and Rizwan, 2021; Suman, *et al.*,2021). A numerical model is formulated referring to the aforementioned phases of hunting. In the first place, the encircling manner is numerically modelled using equations (5.24) and (5.25) as follows (Suman *et al.*, 2021; Bilal and Rizwan, 2021):

$$\overrightarrow{C} = \overrightarrow{\mu_2} \,.\, \overrightarrow{L_p}(i) - \overrightarrow{L_g}(i) \tag{5.24}$$

$$\overrightarrow{L_g}(i + 1) = \overrightarrow{L_p}(i) - \overrightarrow{\mu_1} \,.\, \overrightarrow{C} \tag{5. 25}$$

$\overrightarrow{\mu_1}$ and $\overrightarrow{\mu_2}$ in above equations represent the coefficient vectors of targeted victim. These vectors are computed using Equations (5.26) and (5.27) as follows (Suman et al. 2021; Bilal and Rizwan, 2021):

$$\overrightarrow{\mu_1} = 2 \times \overrightarrow{A}.\overrightarrow{R_1} - \vec{A} \tag{5 26}$$

$$\overrightarrow{\mu_2} = 2 \,.\, \overrightarrow{R_2} \,. \tag{5. 27}$$

where, $\overrightarrow{L_g}(i)$ and $\overrightarrow{L_p}(i)$ stand for the location of the wolves and the victim in the ith iteration. Magnitudes of $\vec{A}$ diminish linearly starting from 2 to 0 in the course of iteration. $\overrightarrow{R_1}, \overrightarrow{R_2}$ represent arbitrary vectors in the range of 0 to 1. As it has been explained before, the process of surrounding the victim is headed by the, β and δ. After the accomplishment of the encircling, another phase of finalizing the process is implemented by the leading group of grey wolves from their respective locations. This final stage is mathematically expressed in equations (5.29) (5.30) and (5.31) as follows (Bilal and Rizwan, 2021; Suman *et al.*, 2021):

$$\overrightarrow{C_\alpha} = \left|\overrightarrow{\mu_2}[1] \times \overrightarrow{L_\alpha} - \overrightarrow{L_p}\right|,\ \overrightarrow{C_\beta} = \left|\overrightarrow{\mu_2}[2] \times \overrightarrow{L_\beta} - \overrightarrow{L_p}\right|,\ \text{and}\ \overrightarrow{C_\delta} = \left|\overrightarrow{\mu_2}[3] \times \overrightarrow{L_\delta} - \overrightarrow{L_p}\right| \tag{5.28}$$

$$\overrightarrow{L_p}[1] = \overrightarrow{L_\alpha} - \overrightarrow{\mu_1}[1] \times \overrightarrow{C_\alpha},\ \overrightarrow{L_p}[2] = \overrightarrow{L_\beta} - \overrightarrow{\mu_1}[2] \times \overrightarrow{C_\beta},\ \text{and}\ \overrightarrow{L_p}[3] = \overrightarrow{L_\delta} - \overrightarrow{\mu_1}[3] \times \overrightarrow{C_\delta} \tag{5.29}$$

$$\overrightarrow{L_p}(i + t) = \frac{\overrightarrow{L_\alpha}[1] + \overrightarrow{L_\beta}[2] + \overrightarrow{L_\delta}[3]}{3} \tag{5.30}$$

$\overrightarrow{\mu_1}$ denotes an arbitrary value lies in the range starting from $-2A$ to $2A]$. If $|\mu_1|$ is lower than 1, grey wolves are required to attack the victim. If $|\mu_1|$ is larger than 1, grey wolves are compelled to go away from the victim.

5. 8.2.6 Execution of GWO method for optimal system sizing

Following are the important steps of executing GWO method for the optimal system sizing (Bilal and Rizwan, 2021; Suman *et al.*, 2021):

(i) Preparing the magnitude of the population and input variables of GWO
(ii) Establishing the search representative and produce the parameters arbitrarily(Selecting randomly the quantity of solar PV modules and biogas power generating units from relevant constraints)
(iii) Estimating the amount of batteries after the computation of the total produced energy by renewable energy sources of the system by taking into account the reliability (Obtain the feasible population subject to the predefined LEPP value from relevant constraints).
(iv) Feeding the decision variables to the formulated objective function (Equation 23) from the set of feasible population and calculate total NPC
(v) Selecting the least total NPC acquired from the feasible populations equal to the population size. The NPC is assumed as the finest fitness for the first iteration.
(vi) Updating the location of exploration agents, while t $<$ the greatest sum of repetitions and randomly compute the amount of solar PV modules and
(vii) Computing the formulated objective function of new exploration agents by estimating the quantity of batteries.
(viii) Determining the new finest exploration agents and substitute it with old finest exploration agent, knowing that the new is superior to the old finest exploration agent.
(ix) Terminating condition is it fulfilled? If it is not, repeat the step (ii) and if the condition is satisfied then move to a next step.
(x) Determining the optimal size (optimal parameters including the least value of LCOE) of the proposed energy system and finalize the GWO method

There are two main conditions have been used during modelling strategy to consider for LEPP evaluation with respect to the energy demand in the entire process of optimization:

Condition 1: When SPV panel is generating surplus power in comparison with authentic energy demand

Condition 2: When SPV panel is generating less power in comparison with authentic energy demand

5.9 SYSTEM RELIABILITY AND SENSITIVITY ANALYSIS USING GWO ALGORITHM

Prior to the carrying out the sensitivity analysis, techno-economic analysis of off- grid HRESS is carried out using GWO method in addition to HOMER software. In this first case the system is assumed be balanced meaning that generated power supply and load demand are balanced. In such a condition there is no shortage of energy. However, this condition practically cannot be always be maintained as generated power varies periodically. In the second case, the analysis of the system is further investigated by the variation of LEPPs. Here, the designed system is assumed to generate power less than the generation power capacity. In this context generated power supply and energy demand are not balanced implying a shortage of power. This section of the research article presents the system optimization and sensitivity analysis.

5.9.1 The Uppermost and Lowermost of LEPP

LEPP can be computed using Equation 5.42 after the determination of the shortage of power supply using equation (5.43). For the straightforwardness of calculating the LEPP, in this study the equation (5.15) can be simplified into the equation (5.31) as follows (Hadidian-Moghaddam *et al*., 2016):

$$UES_{(t)} \;\; = E_{L(t)} - \; (\, G_{SB}(t) + G_{btt\ bank\ (t)} \; , \tag{5.31}$$

If power generated from renewable energy sources plus stored power in the battery bank satisfies all energy required for 100 %, equation (5.32) rewritten as equation (3.33). LEPP can be estimated using equation (5.16) as follows (Hadidian-Moghaddam *et al*., 2016):

$$UES_{(t)} = E_{L(t)} - 100\% * E_{L(t)} \; , \tag{5.32}$$

$$UES_{(t)} = 0, \tag{5. 33}$$

Using the GWO method, appraisal of the objective function consistent with the delineated constraints is made. Sizes of components are selected within the stated limits. Identification of viable configurations of the hybrid system is done in relation to the pre-set magnitudes of

LEPP. The best possible solutions are repeated in the GWO method. The structure is updated to estimate the minimum total NPC. LEPP is determined by substituting Equation 33 into Equation 16 which equals to zero. It implies that the system satisfies power supply requirement when LEPP = 0. Also, the system is also assumed to produce power not lower than 93 % of the whole load giving highest value of LEPP equals to 0.07. Values of LEPP for the sensitivity analysis are evaluated with similar approach. Here, the hybrid energy system is assumed to generate power of 96% and 94 % of total actual load yielding LEPP values equals to 0.04 and 0.06 respectively. Table 5.11 specifies miscellaneous specifications for GWO technique.

Table 5.11: Miscellaneous specifications for GWO technique

Parameters	Value
Population size of grey wolves n	12
Maximum number of iterations, $iter_{max}$	100
Inflation rate	6 %
Interest rate	3.04 %
Highest capacity of biogas generator $\boldsymbol{P_{BIOG}^{maxi}}$	25 kW
Highest quantity of solar panels $\boldsymbol{N_{PV}^{maxi}}$	100
Highest quantity of batteries $\boldsymbol{N_{btt}^{maxi}}$	764
Highest quantity of converters $\boldsymbol{N_{CONV}^{maxi}}$	20
Highest LEPP, $\boldsymbol{LEPP^{maxi}}$	0.07

5.9.2 Comprehensive Methodology for Sizing the Proposed HRESS using GWO Algorithm

Optimization parameters such as solar radiation, animal wastes, and electrical load data and assumed constants (data sheet) were used as input variables. Decision variables like A_{pv} and P_{BIOG} were estimated by GWO algorithm for individual iteration. Then, the power from solar PV (P_{pv}) and biogas generator (P_{BIOG}) were estimated with variable inputs, assumed constant inputs and approximated decision variables. In order to meet the energy requirements, the potential of solar energy is considered to be maximized deliberately so as to use an advantage of free fuel in comparison with the biomass in this case animal wastes. However, if generated electricity from aforesaid energy sources does not satisfy the load demand, stored energy from batteries is used to balance power supply and demand. The standards of LEPP were calculated for the total time in hours for a year equivalent to 8760 hours. In case any value of LEPP has been greater than the prescribed one, the decision values were then recalculated. If there was no any deviation from the predetermined value, optimization procedure was implemented. Then, the optimal size of the hybrid system is obtained corresponding to the lowermost total NPC (also LCOE) which is computed at LEPP equals to zero when the power supply and demand are equally balanced (Jamshidi and Askarzadeh, 2019).

5.10 RESULTS AND DISCUSSIONS

The key objective of this research work such as power capacity and cost optimization of the off-grid HRESS for generating electricity matching the needed load demand of the specified location under study has been mentioned in the beginning of the study. In relation to the given data, the optimization of the proposed off-grid HRESS has been implemented using HOMER pro software and GWO method developed in MATLAB.

5.10.1 Results by HOMER Platform

This part provides the results obtained from HOMER pro software. These results include optimization results, results related with sensitivity, financial and environmental analysis.

5.10.1.1 Optimal Results

In this work, the optimal configuration of the off-grid HRESS system components in this case study is a 40 kW PV, 25 kW BIOG, 144 Generic 1kWh Li-ion batteries, four in series with 36 strings of system bus voltage 24V and 40 kW converter with a dispatch strategy of cycle charging. This RE system comprises of annual scaled solar radiation, scaled annual biomass average and biomass/biogas price is 6.11 kWh/m^2/day, 0.2 ton/day and $ 3.00/tonne respectively. Figure 5.2 indicates the optimum lowest cost off-grid HRESS. Total NPC, investment cost, LCOE for the HRESS are $ 106,383.50, $78500 and $ 0.1109/kWh respectively. Electrical production for PV and BIOG are 72,500 kWh/year and 7706 kWh/ year respectively. Therefore, total electrical production of the off- grid HRESS is 80, 206 kWh/year. In this case, HRESS is the proposed optimally designed RE based system combining PV and BIOG and batteries. Figure 5.12 represents the graphs for power outputs and electricity production according to the selected components constituting off-grid hybrid PV/BIOG/BATTERIES. Power output generated by PV is higher than that of BIOG. Capacity factors for PV and BIOG are 20.7 % and 3.52% respectively Similarly, electricity production for PV/DG/BATTERY and DG only are 77 210 kWh and 779640 kWh/ year respectively. Electricity production for PV/DG/BATTERY and DG only are also indicated in Figure 2. 13. and Figure 2.14 respectively. Figure 2.15 portrays a summary of cash flows by components for proposed off- grid hybrid PV/BIOG/BATTERY system. The investment prices for capital for batteries, BIOG, PV are $ 36, 000, $ 6500, and $ 28, 000 respectively.

The capital price for batteries is the highest equivalent to 45.9% followed by cost of PV with 36.7 %. Initial cost for BIOG is 8.3% and thus is the lowest. Also, O&M prices for batteries, BIOG, PV are $ 3, 429.92, $ 10, 825.67, and $ 952.75 respectively. BIOG has highest O&M about $ 71.2 followed by same category cost of 22.6%. PV has the lowest O&M cost around 6.3 %. Similarly, Figure 16 displays cash flow summary by components off- grid hybrid PV/DG/BATTERY system. The initial costs for batteries, DG, PV are $ 36, 000, $ 2 053.06, and $ 28, 000 respectively. Total NPC for the whole system is $ 122031.06. NPC for batteries is the highest equivalent to 39.2 % followed by cost of DG backup with 27.6 %. NPC for BIOG is 23.7 %. As stated in the cost type in Fig. 16, initial cost is the highest accounting 60.68% of total NPC. In the same line, if DG only is used continuously (Kohler 89 kW) to supply the load total NPC is $4.3 million, COE is $ 4.52/kWh while operating cost is $ 272726.40. Initial cost for the device is actually lower than running cost of the machine and therefore is expensive due to fuel cost. Capital for the machine and running cost for fuels are $ 6310 (0.14%) and $ 3.8 million (88.76 %) of the total NPC respectively.

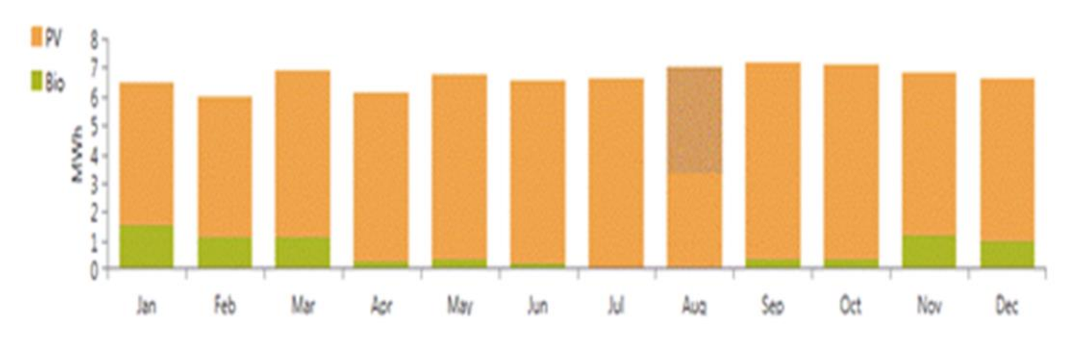


Figure 5.12. Annual monthly electric production of hybrid PV – BIOG-battery storage system

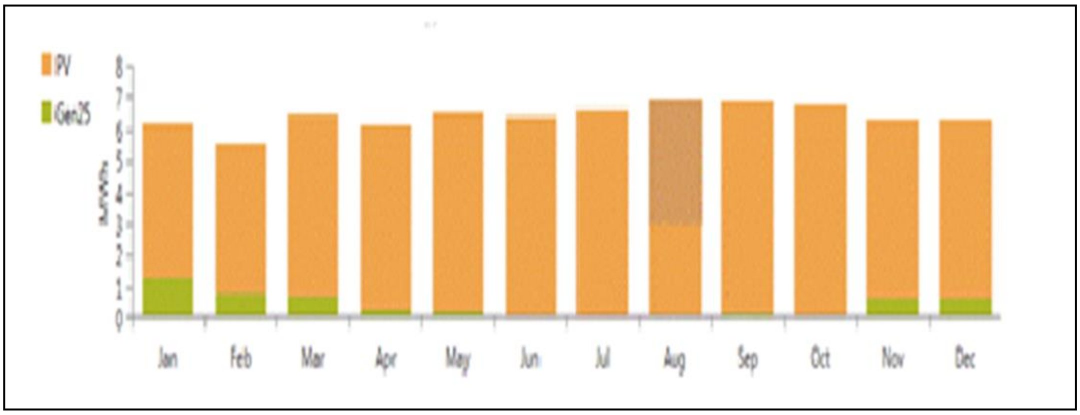


Figure 5.13. Annual monthly electric production of hybrid PV and DG backup

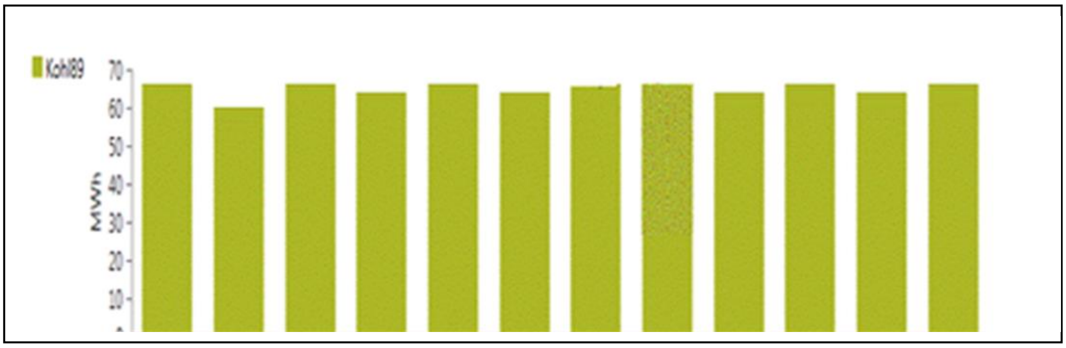


Figure 5.14. Annual monthly electric production DG only

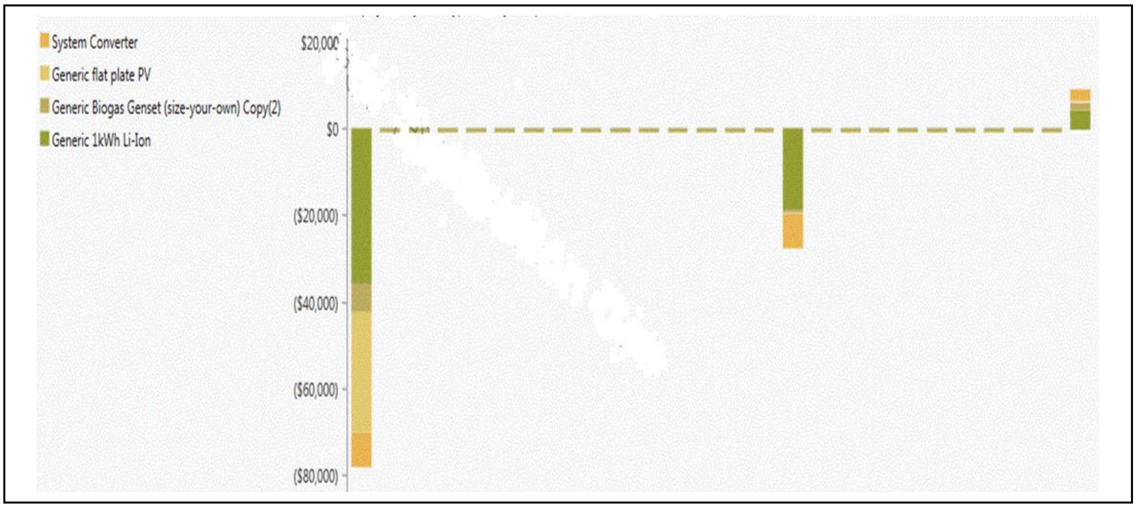


Figure 5.15. Cash flow summary for the selected components of hybrid PV/BIOG/BATTERY system

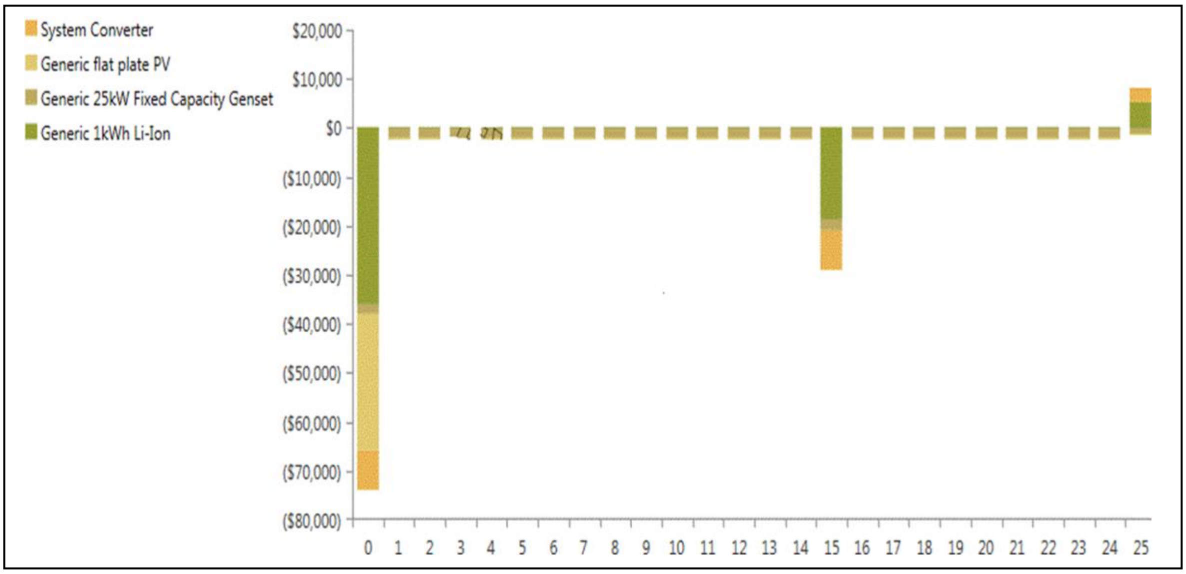


Figure 5.16. Cash flow summary for the selected components of hybrid PV/DG/BATTERY

5.10.1.2 Optimal Off-Grid HRESS versus Other Technologies

Optimization results are presented by comparing proposed optimized system with other technologies, three scenarios have been formulated: Scenario 1 represents PV-BIOG-Battery storage Hybrid system, scenario 2 defines PV- DG- Battery storage Hybrid system and scenario 3 describes DG system.

(a)Evaluation of electrical power generation and load

Evaluation of electrical power analysis offers details on power generation as explained by the assumed scenarios. Here, it should be recapped that the monthly electric generation of PV/BIOG/BATTERIES, PV/DG/BATTERIES and DG only is shown in Figure 12. , Figure 13, and Figure 14. Respectively and results for electric power based on the three scenarios are summarized in the Table 5. 12.

Table 5. 12: Summarized results of evaluation of electrical power and load

Parameter	Scenario 1	Scenario 2	Scenario 3
Solar PV production	72 500 kWh/yr.	72 460 kWh/yr.	NA
BIOG production	7707 kWh/yr.	NA	NA
Battery annual throughout	29 961 kWh	29150 kWh/yr.	NA
DG in hybrid production	NA	4750 kWh/yr.	NA
Single DG production	NA	NA	779640 kWh/yr.
Renewable fraction (%)	100	92.1	0
Fuel consumption	23.1 tons/yr.	1610L/yr.	242 302 L/yr.
Unmet electrical load	0	0	0
Excess electrical power	6930 kWh/yr.	10 725 kWh/yr.	134 524 kWh/yr.
Capacity unavailability	0	0	0

NA = Not applicable

(c) Financial analysis

Financial analysis has been performed using financial variables of LCOE and NPC. Table 5.13 indicates summarized results of financial appraisal.

Table 5.13: Summarized results of financial evaluation

Technology	Investment cost ($)	Replacement cost ($)	O & M cost ($)	Fuel cost ($)	Salvage ($)	Total ($)
Scenario 1						
Solar PV	28 000	0	952.75	0	0	28952.75
BIOG	6500	0	10825.67	1081.64	967.31	17440
Batteries	36 000	10905. 84	3429.92	0	1848.80	48484
Converter	8000	4541.86	0	0	1038.03	11503.83
System	78500	15447.7	15208.35	1081.64	3854.14	106383.55
Scenario 2						

Solar PV	28000	0	952.75	0	0	28952.75
DG set	2053.06	2053.06	6396.46	25569.55	293.03	33725.74
Batteries	36000	10700.36	3429.92	0	2281.55	47848.72
Converter	8000	4541.86	0	0	1038.03	11503.83
System	74053.06	15242.22	10778.83	25569.55	3612.61	122031.06
Scenario 3						
DG set only	6 310	56 273.09	425652.67	3847566.29	982.49	4334819.56
System	6 310	56 273.09	425652.67	3847566.29	982.49	4334819.56

5.10.1.3 Economical Comparison Through BGE Distance

Breakeven grid extension distance is compared with the optimal standalone system. Breakeven grid extension distance is the minimum distance that makes the LCOE of standalone system cheaper than LCOE in expanding the grid. Negative distance value means that LCOE of off-grid micro power system is always cheaper than that of grid expansion whereas positive distance implies that LCOE of the off–grid system is cheaper than that of grid extension beyond such a distance. Below this break-even distance grid extension (EDL) is cheaper than HRESS and is not economically viable beyond the distance In scenario 1, break even grid extension distance is 0.19 km whereas NPC and LCOE are $ 106,383.50 and $ 0.1109/kWh respectively. In scenario 2, break even grid extension distance is 0.48 km whereas NPC and LCOE are $ 122, 031.10 and $ 0.1273/kWh respectively. In scenario 3, break even grid extension distance is 77.5 Km whereas NPC and LCOE are $ 4,337,089 and $ 4.52/kWh respectively. Figures 5.17 and 5.18 show comparison of BGE distances versus scenario1, scenario2 and scenario for total NPC and LCOE respectively.

Linear equations (3.34), (3.35), and (3.36) have been formulated for drawing the graph for comparing NPC and breakeven grid extension of the solar PV/BIOG/BATTERY, PV/DG/BATTERY, and DG only respectively as follows:

$$y_1 = 559913.2\, x_1 - 0.008 \qquad (3.34)$$

$$y_2 \ = 254231.5\, x_2 - \ 0.02 \qquad (3.35)$$

$$y_3 = 55962.4\, x_3 \ + 3 \qquad (3.36)$$

Note 1: All “y” and “x “indicate total NPC and breakeven grid extension distance respectively.

Similarly, linear equations (5.37), (5.38), and (5.39) have been formulated for drawing the graph for comparing LCOE and breakeven grid extension of the solar PV/BIOG/BATTERY, solar PV/DG/BATTERY, and DG only respectively as follows:

$$y_4 = 0.5837x_4 - 0.000003 \tag{5.37}$$

$$y_5 = 0.2652\, x_5 + 0.000004 \tag{5.38}$$

$$y_6 = 0.0583\, x_6 + 0.00175 \tag{5.39}$$

Note 2: All "y" and "x "indicate total LCOE and breakeven grid extension distance respectively.

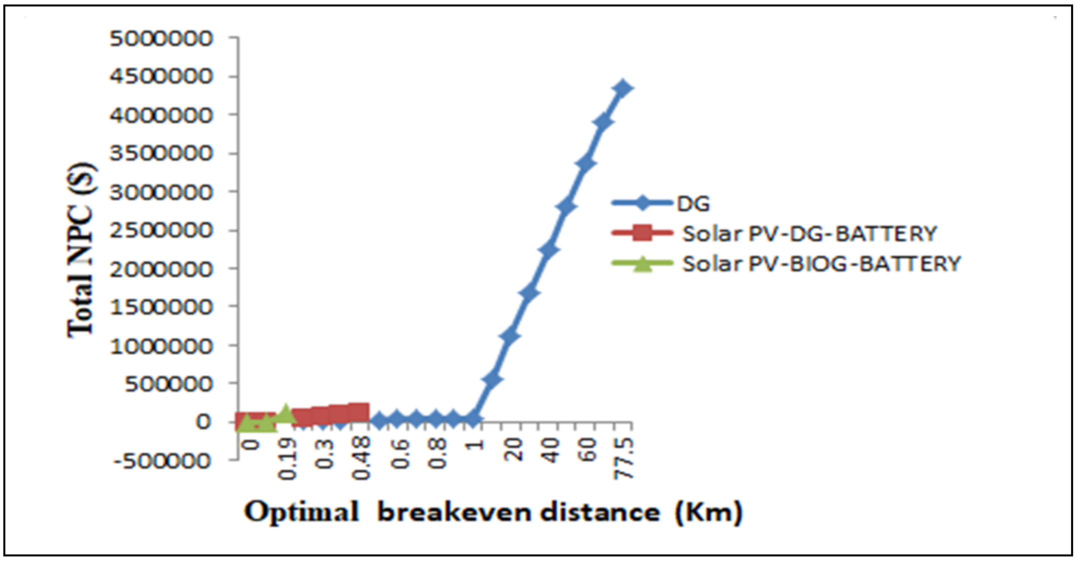


Figure 5.17. NPC for hybrid PV-BIOG-BATTERY, PV-DG-BATTERY, and DG versus break even distance

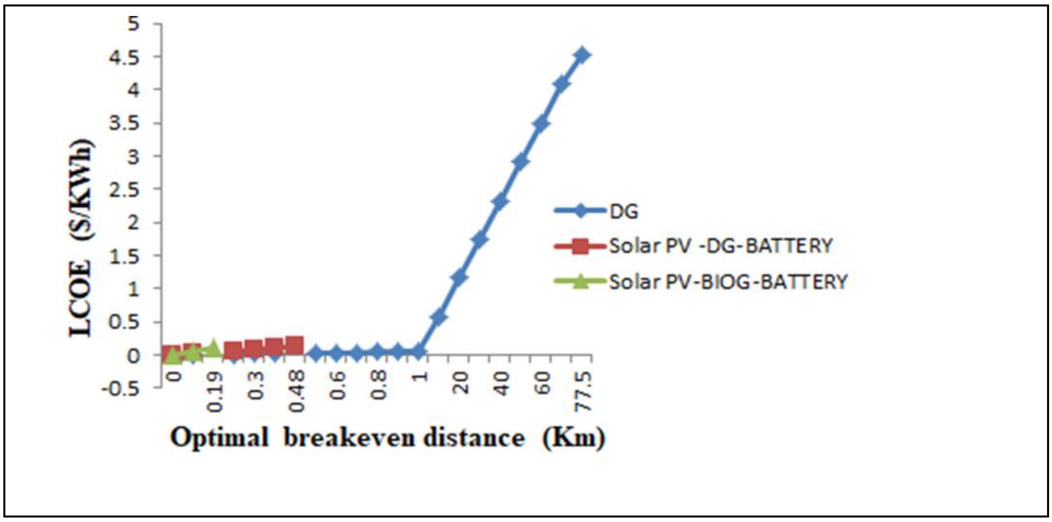


Figure 5.18. LCOE for hybrid PV-BIOG-BATTERY, PV-DG-BATTERY, and DG versus break even distance

5.10.1.4 Results of Sensitivity Analysis

Input variables such as variations in electricity supply requirement, energy resources and fuel costs. Several sensitive input parameters are taken into account for the selection of optimal configuration of off-grid HRESS to meet the energy demand. Sensitivity analysis indicates that an increase of annual scaled solar radiation from 6.11 to 7. 5 kWh/ m^2/day at fixed biomass feedstock and electrical load reduces the total NPC, LCOE and operating cost of the optimized system. The total NPC, LCOE and operating cost of proposed optimal off-grid hybrid PV/BIOG/BATTERY are $ 106,383.50, $ 0.1109/kWh and $ 1755.95 respectively which are reduced to $ 101, 584, $ 0.106/kWh and $1454 respectively. Similarly, the total NPC, LCOE and operating cost when backup system is DG instead of BIOG, that is, hybrid PV/DG/BATTERY are $ 122031.10, $ 0.1273/kWh and $ 3021.43 respectively which are reduced to $ 109700, $ 0.114/kWh and $2245 respectively

5.10.1.5 Results of Environmental Analysis

Impact of greenhouse gas (GHG) emissions produced from the proposed optimal off-grid HRESS consisting of PV, BIOG and batteries are also compared with GHG emissions from assumed technologies. Table 5.8 indicates the comparison of GHG emissions produced by the proposed 100% RE micro power system (HRESS) versus other technologies under specified scenarios. Table 5.14 shows the comparison of the GHG emissions produced by the proposed 100% RE micro power system (HRESS) versus other technologies under specified scenarios

Table 5.14: Comparison of the GHG emissions produced by the proposed 100% RE micro power system (HRESS) versus other technologies under specified scenarios

Pollutant	Scenario1 (PV/BIOG/BB)	Scenario 2 (DG/BIOG/BB)	Scenario 3 (DG only)	Unit
Carbon dioxide	0.531	67 641	635, 966	kg/year
Carbon monoxide	0.00589	422	2 908	kg/year
UNHC	0	18.6	174	kg/year
Particulate matters	0	2.53	15.4	kg/year
Sulphur dioxide	0	166	1553	kg/year
Nitrogen oxide	0.00368	397	308	kg/year

UNHC = Unburned hydrocarbons

5.10.2 Results Obtained by GWO Method

This specific part of the research article presents the optimization and sensitivity results of the off-grid HRESS achieved via application of GWO platform as follows:

5.10.2.1 Optimization results of balanced generated power supply-demand system (LEPP = 0)

As it has been mentioned before, the average daily electricity consumption is 511. 1 kWh /day (Baseline), peak power capacity 30.31 kW, and load factor is 0.71. For the hybrid electric system to supply sufficient power to satisfy the load generated electricity should be equal or greater than the highest power capacity. The off-grid HRESS has been optimized when LEPP equals to zero denoting that no shortage of power. In other words, generated power supply and energy demand are well balanced.

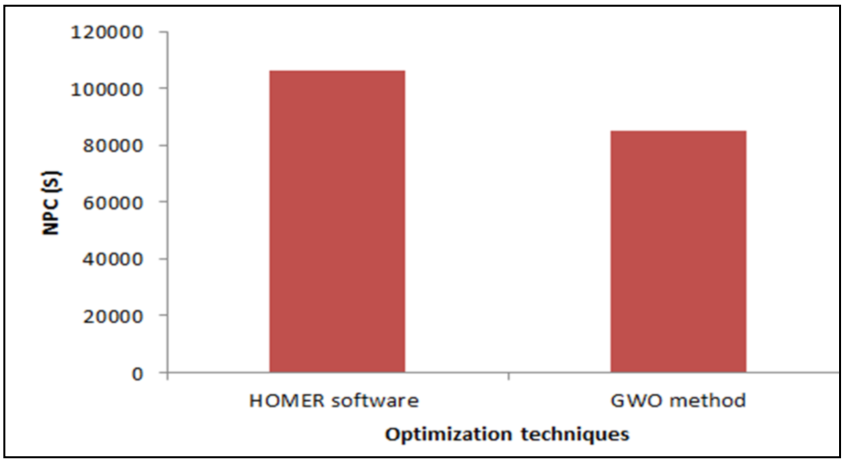


Figure 5.19. Graph of NPC for off-grid HRESS using HOMER platform and GWO algorithm (LEPP = 0)

The analysis of the optimized system by GWO method shows that over-all NPC and LCOE are $ 85, 106 A and $ 0.0887/kWh respectively

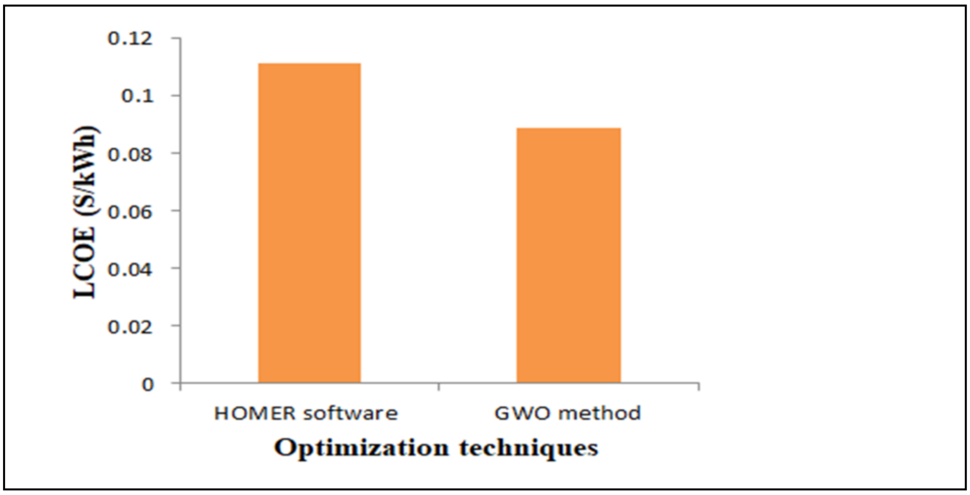


Figure 5.20. Graph of COE for off-grid HRESS using HOMER platform and GWO algorithm (LEPP = 0)

The use of AI optimization technique (GWO) has further reduced the financial metrics of power generation up to around 20 % when compared with soft computing tool (HOMER).

Figure 5.19 and Figure 5.20 indicate the graphs of NPC and LCOE of off-grid HRESS respectively using HOMER platform GWO method (LEPP = 0).

5.10.2.2 Sensitivity analysis results of unbalanced generated power supply-demand system

The sensitivity analysis is carried out to find out the effect of system reliability in reflection to financial performance. Here, assumption is made that generated power and energy demand are unbalanced (Huang, Yang et al. 2018) [75]. The application of GWO algorithm is employed by considering the unbalanced condition of the designed system. In this research article, LEPP is considered to be the sensitivity's variable thus the analysis of the optimized system has been evaluated based on the variation of estimated magnitudes of LEPP, that is, specified values of 0. 04 and 0. 06.

It has been witnessed that when LEPP equals to 0.04, the configuration of off-grid HRESS reveals the overall NPC of $ 79 545.992 and LCOE of $ 0.0316/ kWh. The variation of overall NPC of the designed off-grid HRESS is now less than that in balanced energy system when LEPP equals to zero. The diminution in extra power can be ascribed owing to the reduction in the capacity of the solar PV array. Similarly, when LEPP equals to 0.06, off-grid HRESS configuration has overall NPC of $ 71747.36 and its corresponding LCOE equals to $ 0. 0.0102/ kWh. It implies that at given condition of LEPP which equals to 0.06, the overall NPC of optimal HRESS is further decreased up to at least 20 % in comparison with balanced condition of generated capacity and energy demand.

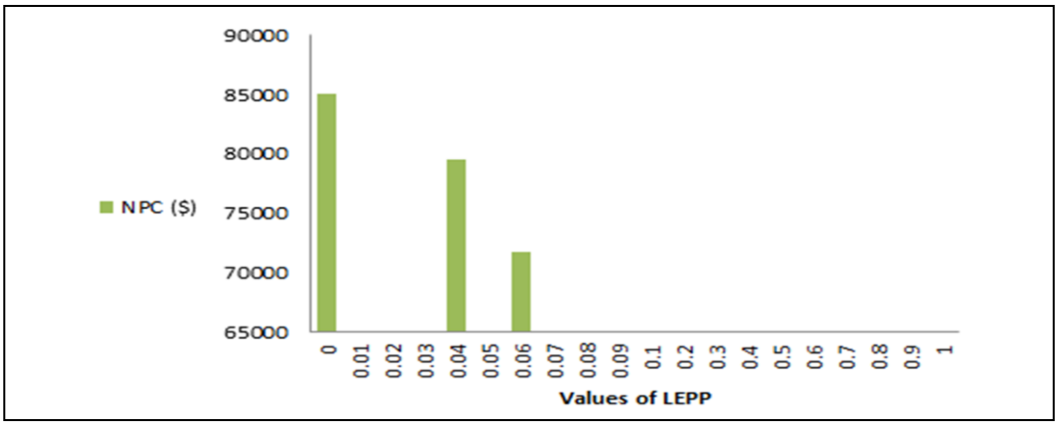


Figure 5.21. Graph of NPC for optimization and sensitivity results of the system by GWO method

The extra power generation is minimized owing to the decline of the capacity of solar PV module. In this case maximum power of the designed system is not taken into account and attributed to the reduced extra power. Figure 5.21 and Figure 5. 22 indicate the graphs of NPC and LCOE for optimization and sensitivity results by GWO method.

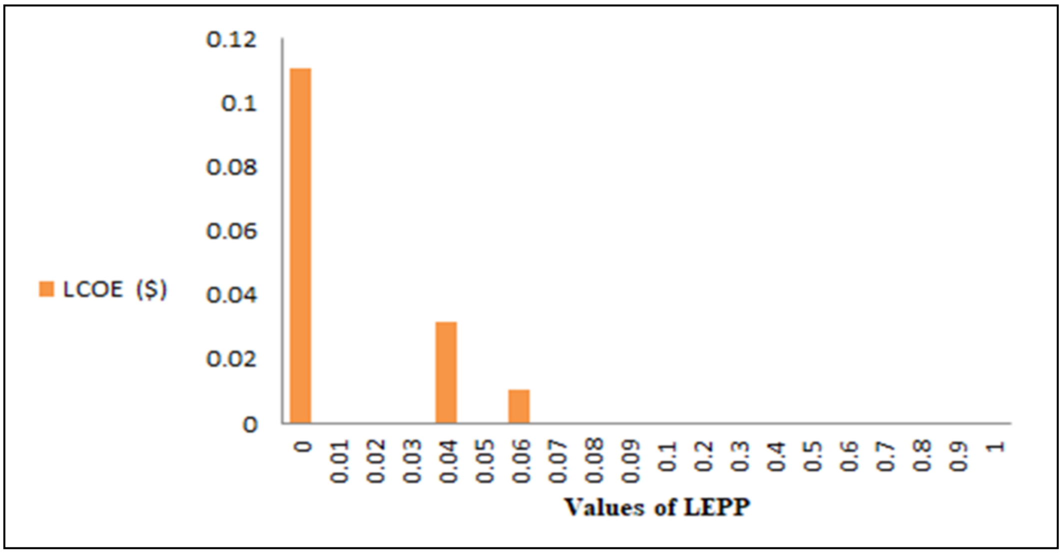


Figure 5.22. Graph of LCOE for optimization and sensitivity results of the system by GWO method

5.11 COMPARISON OF FINDINGS ACQUIRED FROM OTHER RELATED CONFIGURATIONS

For the purpose of understanding clearly the importance owing to application of GWO algorithm, the performance of the proposed off-grid HRESS (presented in this paper) is related with the other optimal hybrid renewable energy-based systems consisting similar configurations consisting of renewable energy sources, that is, solar PV and biogas fuel . Dissimilarities are mainly in terms of storages, electrical loads, and metaheuristic optimization approaches. The comparison of results from other related configurations is discussed as follows:

First, the proposed HRESS is compared with the system consisting of solar PV, biogas fuelled generator and storage system comprising of batteries and hydro pumped storage system (Das *et al.*, 2019). The system employs one upper reservoir without the lower one (Das *et al.*, 2019). The system is designed to power radio transmitter with power capacity, consumption and load factor are 25.54 kW, 356. 38 kWh/ day, and 0. 58 (Das *et al*. 2019). The study presents the optimization of the hybrid system using two metaheuristic techniques such as WCA (Water Cycle Algorithm) and MFO (Moth Flame Optimization) which are compared with genetic algorithm (GA) (Das *et al.*, 2019). These techniques have indicated highest convergence rate in the optimization results. WCA shows an area of solar PV panels equals to 548.67 square metre produces power equivalent to 69.2 kW, biogas fuelled generator capacity is 16 kW, number of batteries equals to 21, capacity of the converter is 30 kW, capacity of top reservoir is 2081.5 cubic meters, total NPC is $ 813, 319 and LCOE is $ 0.4864/ kWh(Das *et al*., 2019). Similarly, MFO indicates an area of solar PV modules equals to 549.2 square metre produces power equivalent to 69.3 kW, capacity of biogas driven generator is same as in WCA, amount of batteries is same as in WCA, capacity of the converter is same as in WCA, capacity of upper reservoir is 2083 cubic meters, total NPC is $ 813, 865 and LCOE is $ 0.4865/ kWh (Das *et al.* 2019).

Second configuration, the HRESS is also compared with the configuration containing solar PV, bio-waste and fuel cell (hydrogen storage tank). The configuration is intended to generate power to serve annual load profile equals to 269. 15 MWh reliability (Sun *et al*., 2022). The paper presents the system is optimized using WOA (Whale Optimization Algorithm) method which is PSO (Particle Swarm Optimization) technique by bearing in mind the existence of components for lifetime of 20 years. The optimal system configuration is the cheapest in comparison with other combinations. The system has total NPC of $ 2.820 million and LEPP equals to 0. 0029 reliability (Sun *et al*., 2022). Similarly, LCOE of the same optimal system equals to 0. $ 5238 / kWh reliability (Sun et al., 2022). The suggested optimization method for optimal design of hybrid system is superior to PSO. WOA method presents lower total NPC, accuracy, higher convergence velocity and reliability (Sun *et al.*, 2022).

Third configuration consists of solar PV, battery and pumped storage systems having upper without biogas generator bearing in mind that the proposed HRESS has biogas generator in addition to solar PV but without pumped water storage (Ma *et al*., 2014). The designed system aims at supplying power for an isolated in Hong Kong using renewable energy sources for 100 % (Ma *et al.*, 2014). The daily power consumption and peak power are respectively, 250 kWh and 50 kW (Ma *et al*., 2014). The system provides the viability study and financial analysis of the given energy storage systems. The storage energy systems are investigated in terms of LCC (life cycle cost) and practical feasibility. The analysis using LCC is useful for determining which is more cost-effective between the energy storage by battery bank and pumped water (Ma *et al*., 2014). The study has compared three options such as novel deep cycle battery, traditional battery, and combined pumped hydro and battery energy storages. The LCC and LCOE for the optimal storage system combining pumped hydro and battery energy storage schemes are S 2394.901 and $ 1916/ kWh respectively (Ma *et al*., 2014).

Fourth configuration is also constituted by solar PV, biogas power system and battery storage system. The system has been analysed using a deterministic method to satisfy a proportional scaled down demand of Kenya, one of the countries located in East Africa (Lai and McCulloch; 2016). In the paper, it has been assumed that solar panels covering area equivalent to 20000 square metres produces capacity of 5 MW. Also, biogas generator can produce power only if the power output declines below 40 % of the rated size (2.4 MW) while its efficiency is 70 % (Lai and McCulloch; 2016). The optimal sizing ratio of power generation sources biogas generator to solar PV is 2.4:5. By using PSO algorithm, the study has shown lower LCOE in the hybrid system than that of biogas generator. On the other hand, LCOE becomes lower at discount rate below 8 % and stipulated prices of the system components (Lai and McCulloch; 2016). In 2012, for instance, at discount rate of 8 % with lower and upper boundaries of given costs, the optimal results of LCOEs were found to be $ 0.39/ kWh and $ 0.42/ kWh respectively (Lai and McCulloch, 2016).

Generally, different metaheuristic optimization results indicate an effective design of hybrid energy system with less technical and financial costs as likened with available designs in the literature.

5.12 CONCLUSIONS, RECOMMENDATIONS AND RESEARCH IN FUTURE

In this paper, HOMER and GWO method have been utilized for acquiring the techno-economic analysis of optimal design of PV-BIOG-BATTERY hybrid system for delivering electricity to Simboya village in Mbeya rural district, Mbeya region, Tanzania. Firstly, based on the application of HOMER platform conclusions of this research work are presented as follows: Technical and economic viability analysis for 100 % hybrid renewable electric system has been carried out intending to generate electricity for Simboya village, Mbeya rural district, Tanzania. This study includes optimized design and a comparative study of PV-BIOG-BATTERY, PV-DG-BATTERY and DG only are carried out. Additionally, breakeven grid extension distance of individual aforementioned technology has been evaluated based on the assumption that the micro grid power system may take power from the central grid. Furthermore, the study has performed sensitivity and environmental analyses. The country is located in tropical areas and therefore electrical load profiles for the area of study have been considered same due to lack of extreme climate change variation in a year (Syahputra and Soesanti, 2020). Residential load is equivalent to 50 % of accrued power requirement is the highest. Load for street lighting is the lowest. This study has indicated that the lowest-price hybrid configuration of solar PV-BIOG-BATTERY is capable of meeting the energy demand at LCOE of $ 0.1109/ kWh with almost negligible GHG emissions. This LCOE is equivalent or less than the grid power price from TANESCO in the range of Tanzanian shillings (TZS) 242.2- 306/kWh (0.104 – 0.14 USD/ kWh, 1 USD equals to 2319.55 on 18.09. 2020; Cuesta ,2018; Kanyamyoga, 2020; Shibano and Mogi, 2020). Furthermore, the cost of proposed system is also even less than the projected LCOE by 2035 for renewable based micro-grid in SSA that is expected to drop to $ 0.2/kWh in electricity generation projects with around 90 % renewable energy fraction (Benalcazar *et al.,* 2020). The price of renewable energy based electricity might not all the time be cheap for isolated areas and thus LCOE can further be reduced by support through subsidies based on specific renewable technologies (Moner-Girona *et al*., 2016). This 100 % RE system has the least breakeven grid extension distance about 0.19 km implying the least NPC. Among the three technologies, DG only has highest LCOE and LCC due to highest running cost caused by high fuel cost. LCOE for DG only is at least four times than of solar PV-BIOG-BATTERY hybrid system. The study has also indicated that DG only produces highest GHG emissions. Sensitivity analysis shows that an escalation of yearly scaled solar energy from 6.11 to 7. 5 kWh/ m^2/day at fixed biomass feedstock and electrical load demand decreases the total NPC, LCOE and operating cost of the optimal hybrid configuration. Moreover, minimum daily mass equals to 0. 315 tonnes is greater than the estimated daily minimum requirement of biomass which equals to at least 0.2 tonnes. This lowest value can drive a biogas generator to produce power of 25 kW. Estimated residential load for Simboya village is equal to 30 kW and is the highest almost 50% while power consumption for street lighting electrical load is the least being equivalent to 0.5 % of the over-all energy demand .

Secondly, in conformity with the application of GWO technique the conclusions of this study are provided as follows: Results of the techno-economic analysis of the optimal HRESS when generated power and energy demand are matched (LEPP= 0) have been presented. The sensitivity analysis of the techno-economic analysis of the system for the assumed values of LEPPs (LEPP = 0.04 & LEPP = 0.06) more than zero, has indicated that the increased LEPP provides the optimal HRESS with the minimized size of components. In general, application of metaheuristic approach (GWO) has exhibited better techno-economic performance of the off- grid HRESS in comparison with soft computing tool (HOMER platform). In other words, use of GWO technique shows the declination of financial metrics of the system. The optimal

HRESS is a promising solution for providing electricity to rustic and isolated locations including the site under study and other places worldwide with similar situation.

5.13 RESEARCH IN FUTURE

For the future study, the optimal HRESS can be expanded by integrating the system with other energy sources and storage energy systems and further analyzed using advanced approach such as, metaheuristic methods in order to build up the enhanced body of knowledge regarding the solutions to optimization problems.   .

CHAPTER 6

RELIABILITY IMPROVEMENT AND OPTIMIZATION OF SPV-HYDRO-BIOGAS -BATTERY BANK SYSTEM

6.0 GENERAL

Countries' population growth enhances their requirement for energy development in a multitude of sectors. The most of this energy is derived from fossil fuels like as NG (Natural gas) and oil which considerably contribute to greenhouse emanations such as air pollution, carbon dioxide (CO_2), sulphur dioxide (SO_X), and nitrogen oxides (NO_X) (Abban and Hongxing, 2021; Kumar *et al.*, 2022). Owing to the unceasing of economic progress worldwide particularly in developing countries like China and India, CO2 emissions are also continuous (Javed and Cudjoe, 2022). The main reasons is because is there is e much over dependence on fossil fuels. Similarly, Tanzania as one of the members of East African Community (EAC) countries can also contribute to the global harmful emissions due to the use of fossil fuels in its energy sector (Dumor *et al.*, 2022) . It is forecasted that over next 50 years, one of the world's most important concerns will be energy scarcity, which is another reason many governments are moving to the deployment of renewable energy-based systems (Gollakota and Shu, 2022). Electricity generation always has been a crucial subject, and numerous researches employing various components have been done. For example, in isolated and rural regions, employing diesel generators which is coupled alongside solar arrays and battery energy storage system is cheaper than an individual DG system. According to studies, the cattle sector accounts for around 36% of NH4 (methane gas) output. Because of the uncertainty surrounding the use, for example of (WT) wind turbines and solar (PV) modules in energy production, hybridised energy-based systems, energy storage devices and backup systems, have been developed (Zheng *et al.*, 2018; Luo et al., 2020). Research into hybridizing diverse renewable sources has revealed that combining solar and biomass resources can cut emissions and generate electricity while lowering energy prices compared to diesel generators, as well as sell surplus energy in inter-connected systems to grid network (Jahangir *et al.*, 2022). A hybrid system with molten carbonate fuel cells, biogas turbine, molten and a super critical carbon dioxide cycle was investigated. According to the findings, the biomass gasifier has indicated to be the most effective in destroying exergy. The sensitivity analysis also found that the price of electricity may reach 0.105 $/kWh. It was also revealed that the hybrid system, as built, can save up to 1050 tonnes of CO2 each year. Due to the high cost of rural grid extension, research was done in China to investigate the viability of creating hybrid biogas/wind/solar energy systems. The HOMER programme was employed in the study, and the results showed that hybrid energy systems provide both environmental and economic merits in remote places. In conjunction with HOMER software, the Jaya algorithm can be employed to size micro - grids. The Jaya algorithm has been used to construct and investigate a wind- biomass- solar energy system in 2020 (Tazay *et al.,* 2020). The scenario provided had 13 solar energy-based systems, four biomass energy based systems, and a single WT. Another study suggested that biogas systems might be employed in MCGs for long-term energy storage. Furthermore, the research showed that battery packs are an ideal alternative for short-term power storage in HRESS. The biomass/solar/battery energy system was 22% more expensive than the fossil fuel alternatives. To satisfy the electricity needs of Bangladeshi refugee camps, a MCG structure with minimal cost and emissions values was created. Among the designed scenarios, the solar- wind- generator- battery bank system with LCOE of 0.35 $/kWh was chosen as the best option. In this scenario, renewable technologies provided 87 percent of the electricity. The research showed that HRESSs are not just financially viable, but are also environmentally friendly (Neves *et al.*, 2021). Micro grids were researched for usage in Pakistan's rural areas. Diesel and biogas generators, solar modules, and WTs were investigated in both off-grid and on-grid environments. According to the data, on-grid solutions are less expensive than off-grid alternatives. The on-grid COE was found to be lying in the range of 0.072 to 0.078 $/kWh, while the off-grid COE was estimated to be in the range of 0.145 to 0.167 $/kWh (Ali *et al*., 2021). An off-grid HRESS was subjected to MOO (Multi Objective Optimization) and MCDM (Multi Criteria Decision Making) approaches derived from biomass. The technology was also used in striling engines and solid oxide fuel cells. According to the findings, the exergy efficiency was 51.54 percent. Furthermore, the optimal net power was calculated to be 572.07 kW. Thus, in addition to generating electricity, HRESSs can be used to extract green fuels (Roy *et al*., 2020). A study on biodiesel production utilising a combination solar/hydro/biomass system was done in 2020.The research found that this design has the potential to provide reduced price and high-yields of green fuels (Mirnezami et al., 2020).

As a result, the national energy policy requires the use of renewable electricity from local energy sources so as to increase access to energy. Tanzanian's government promotes an increase of the share of renewable and clean energy sources by encouraging investment from the non-governmental sector (International and domestic) and increasing the use of domestic capacity.

The HOMER Pro software is widely used in the majority of hybrid renewable energy system research. The HOMER Pro software can combine hybrid renewable and non-renewable energy sources like solar, wind, and fossil fuels (Mirnezami *et al.*, 2020) and calculate all economic and environmental aspects.

Interestingly, because of the large density of cow ranches are normally in rural areas, animal dung yield is particularly high and here hybrid biogas energy system is the main focus of this research work. Anaerobic fermentation is used to turn the animal faeces from these cow grasslands into biogas. Anaerobic fermentation occurs in the absence of oxygen in the existence of naturally arising microorganisms. This biogas contains roughly 65% methane and is a good fuel (Singh, *et al.*, 2022). In order to generate electrical energy, biogas can be combusted with different fuels in a specifically constructed generator. This technology, on the one hand, converts animal dung into energy and, on the other hand, handles the problem of waste recycling (Bharathiraja *et al.*, 2018). Also, majority of the centralized grid network developing countries including Tanzania incurs significant transmission and distribution losses, frequent outages and power shedding specifically when delivering electricity supply to far rural areas. Because of the low reliability and, in certain circumstances, the absence of utility service, renewable energy resources are the only viable solution to rural power needs (Maruyama *et al*., 2019).

However, the fundamental issue is that relying solely on biogas can be costly and is subject to a variety of limitations in comparison with DG source. So, in order to reduce the cost of electricity (COE) and achieve greater stability and reliability, we must use additional renewable energy sources like solar and hydro in hybrid mode (Aziz *et al.*, 2020). If modelled, this off-grid HRESS can be tuned for the optimal LCOE and total net present cost (NPC).

Fortunately, Tanzania has high solar and hydro energy potentials and they are also mature technologies in the country. These energy sources can substantially contribute address the energy poverty in rural areas locally and globally with similar situation. The two power sources can be integrated with biogas to constitute the proposed off-grid HRESS for minimizing cost, enhancing reliability and stability. In addition, based on author's experience, no such study involving proposed off-grid HRESS configuration (100% renewable penetrated system) has been carried out for the selected place.

The main goal of this research work is to support on-going the research and development programmes of looking for the feasibility and developing a practical plan for installing HRESS's in Tanzanian's rural sites with high potential of bio-wastes from livestock sector. For the first time, in the Arusha region, the SIDO (industries development organization) erected 120 floating-drum units. The newly formed parastatal institute CAMARTEC (centre for agricultural mechanization and rural technology) continued to disseminate this technology in the region in 1982. After about a year, practical collaboration between the Tanzanian government and the FRG (Federal Republic of Germany) resulted in the establishment of the biogas extension service (BES) mainly for household applications (Mwakaje, 2008; Roopnarain and Adeleke, 2017). Presently, there is no any commercial hybrid biogas energy based micro grid system has been constructed in the country for electricity generation to supply one of the rural village (Bishoge *et al.*, 2018). Agriculture and livestock keeping are common economic activities in most of the rural areas of developing countries including Tanzania (Mulokozi et al., 2020; Mwantimwa 2020). In other words, most of the families dwelling in rural areas possess at least few cattle and poultry which can produce wastes which can be used for electricity generation if are appropriately managed. In the light of advocating the on–going research and development programmes in the nation, need for proper management of animal wastes and sufficient availability of local renewable energy sources (Zebra *et al.*, 2021) As a prime instance, techno-economic performance analysis of the proposed off-grid HRESS for anticipated power supply to selected area of Simboya village, Mbeya rural district in Tanzania has been implemented. In order to investigate the influence of renewable power sources on carbon emissions reduction, the HOMER Pro software was used to simulate the designs of HRESSs.

6.1 ORIGINALITY OF THE RESEARCH

Large number of researchers has created numerous structures of models regarding hybridized renewable energy-based supply systems (HRESS). According to the present literature plus authors' experience, research gaps are identified and now a proposed innovative model of HRESS is established for modelling and optimizing the off-grid HRESS for provision of electricity in rural areas. The HRESS comprises of micro-hydro-biogas-solar including battery. In first place, HOMER pro software is used as a research platform sizing and optimizing the system. The performance of the system is appraised and likened to other groupings of HRESS for optimum patterns (Diesel generator, grid extension commonly used options in African countries including United Republic of Tanzania) with the lowest economic metrics LCOE and NPC. The optimal arrangement has both economic and ecological merits. This proposed system is cheaper and less pollutant. The following are the project's primary innovations:

(i) The research paper multiplies the diversification of energy sources using the untapped potential of hydro energy systems through the rarely used intervallic tributaries located in the areas characterized by the prolonged climatic conditions of the high rainfall.

(ii) Provides the integration of biogas into the water energy sources of seasonal tributary. This combination is extended by incorporating solar energy system with battery storage mechanism to form an entire off-grid hybrid solar PV-hydro- biogas-battery bank system. The hybrid solar PV-hydro-biogas battery systems are rarely found in Tanzanian environment.

(iii) For each proposed scenario, the ecological evaluation determines the different levels of emissions.

(iv) This research presents BGE (Breakeven Grid Extension) of the proposed off-grid HRESS.

(v) Sensitivity evaluation is also carried out by varying input parameters to such as water flow rate of seasonal tributary, price for the purchased biomass and solar radiation.

6.2. AREA OF STUDY AND METHODOLOGY

In this section, the choice of the place of study, potential of the existing indigenous renewable energy sources, and approximation of energy requirement are described as follows:

6.2.1 Choice of Area of Study

The profile for the selected area of study (Simboya village) is same as explained in the chapters 3, 4, and 5 in Sections (3.3.1.), (4.2.), and (5.4.2.).

6.2.2. Assessment of Energy Requirement

The load has been classified as residential, commercial, institutional, lighting, and Maximum energy requirement for the area of study (Simboya village) is similar as presented in the Chapters 3, 4, and 5 in Sections (3.2.1), (4.2.2.2), and (5.3.2) respectively.

6.2.3 Assessment of the Indigenous Renewable Energy Potential

This section investigates the potential for renewable energy in the local area. Renewable energy sources include solar, small hydro, and bio-waste energy sources from animal wastes and, and data on these sources have been collected.

6.2.3.1 Small hydropower source from the seasonal tributary

The profile of the small hydropower source (The seasonal tributary which is actually located at neighbouring village called Ikukwa village at Ikukwa ward). The hydro energy source is assumed to be located close to the project site in consistent with the definition and of distributed generation supply (A need to be installed close to the site of power utilization to avoid losses and costs that maybe incurred by the long transmission and distribution lines). Therefore, now the hydro energy source is assumed to be close to Simboya village and its details can be referred to the Chapter 7 in the Section (7.2.5).

6.2.3.2 Solar energy resource

Similar assessment of solar energy resource for the area of study (Simboya village) is presented in the Chapters 3, and 5 and 7 in the Sections (3.2.2.1), (5.3.3.1.), and (7.2.6) respectively.

6.2.3.3 Quantification of biogas’s yield from animal wastes

Similar approach of estimating the yield of biogas from animal wastes available at the selected area of study (Simboya village) is presented in the Chapters 5 in Section (5.3.3. 2).

6.3 MODELING OF THE SUB-SYSTEMS OF HYBRID SOLAR PV-HYDRO-BIOGAS-BATTERY BANK

From the explanation above it should be remembered that the optimal off-grid hybrid system includes components such as small water turbine, biogas fuelled generator, solar photovoltaic panels, and energy storage system employing lead acid batteries for supplying AC load. These individual components are also known as sub-systems of the proposed hybrid energy system and are numerically represented for the analysis of its energy management.

Mathematical representation of each sub-system is described in this section. Figure 6.1 indicates the design of integrated components of off-grid HRESS in HOMER platform.

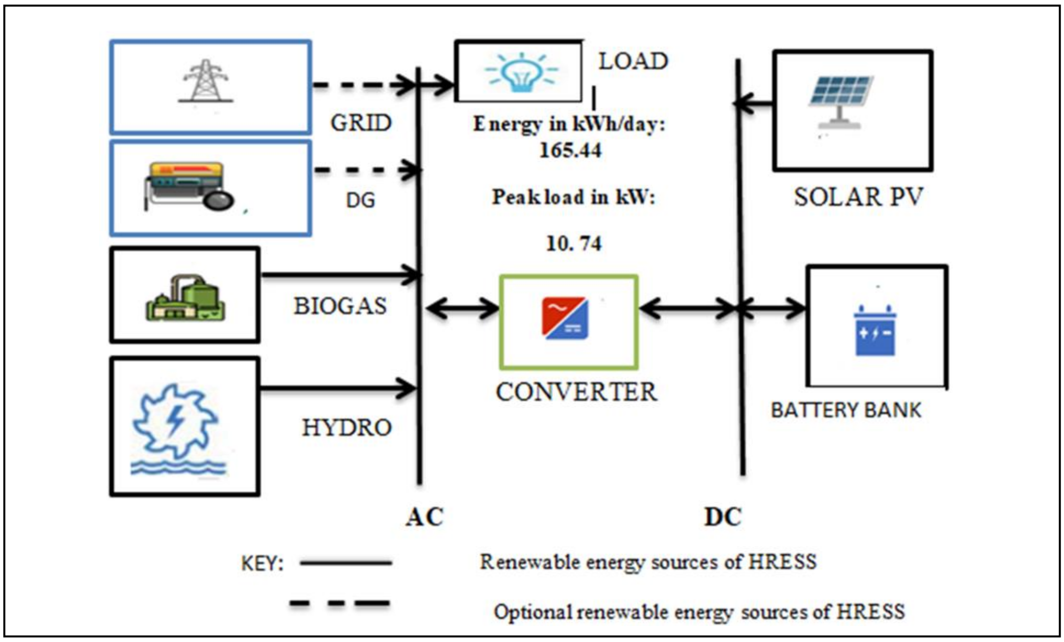


Figure 6.1. Design of integrated components of off-grid HRESS in HOMER platform [Source: Author]

6.3.1 Estimated Power Output of Small Hydro Generator

From the explanation above it should be remembered that the optimal off-grid hybrid system includes components such as small water turbine, biogas fuelled generator, solar photovoltaic panels, and energy storage system employing lead acid batteries for supplying AC load. These individual components are also known as sub-systems of the proposed hybrid energy system and are numerically represented for the analysis of its energy management. Mathematical representation of each sub-system is described in this section.

Hydro energy source from the river is converted into electricity by water turbine. The suitable water flow of the river Q_f $(\frac{m^3}{s})$ is regulated by the highest and lowest turbine ejection. The generated power output E_T from the turbine is also affected by fluctuations in head H_d (m) as a function water flow of the river flow. The H_d varies considerably, particularly where the installations of small H_d are made in the condition of higher water flow rate than rated one appearing at the entry and outlet points of different magnitudes. Apart from the above mentioned factors, also produced energy output E_T (W) depends on other aspects such as the turbine release efficiencyη_T (%), acceleration due to gravitation force g ($\frac{m}{s^2}$), and water density ρ ($\frac{Kg}{m^3}$). Therefore, generated power output from the turbine can be computed as follows (Aziz *et al.*, 2020):

$$E_{HDT} = \rho g Q_f H_d ή_T \tag{6.1}$$

6. 3 .2 Estimated Power Output of Biogas Generator

According to the animal and poultry wastes obtainability, generated power from biogas fuelled generator was calculated using equation (6.2) as follows (Jahangir *et al*. 2022):

$$E_{GEB} = \frac{Obtainability\ of\ biogas\left(\frac{m^3}{day}\right) \times CV_{GEB} \times ή_{GEB} \times \Delta_T}{860 \times \mathrm{H_{GEB}}} \tag{6.2}$$

where, e_{GEB} is generated energy by biogas fuelled system; CV_{GEB} is the calorific value of biogas which is equivalent to 4,700 kilocalories/ Kg; $ή_{GEB}$ is the efficiency of energy system transformation; Δ_{T} is the time taken in hours for the operation of biogas system, and $\mathrm{H_{GEB}}$ refers to the lifetime in hours of biogas fuelled system.

It should also be noted every biogas power source can produce its own output power. For instance, suppose there are three different types of biogas energy sources say S1, S2, and S3. Therefore, expression of total generated power output is provided as follows (6.3) (Jahangir *et al.*, 2022):

$$E_{GEB} = \frac{S_1 + S_2 + S_3}{0.71} \tag{6.3}$$

Renewable energy generation and consumption may be incompatible. At times, this necessitates the usage of batteries during peak consumption periods or when renewable energy generation is reduced for instance at night times when solar arrays are unable to generate electricity.

6.3. 3 Estimated Power Output of Solar PV Generator

Generated output from photovoltaic panel is majorly influenced by the radiated solar energy and temperature. In this specific research work, effects of temperature are ignored for the reason of simplicity and therefore power output E_{PHV} (t) from a solar photovoltaic panel is calculated as in equation (6.4) as follows (Ayvazoğluyüksel and Filik, 2018):

$$E_{PHV}\ (t) = ή_{PHV}\ (t) \times A_{PHV}\ (t) \times I_{PHV}\ (\mathrm{t}) \tag{6.4}$$

Where, $E_{PHV}\ (t)$ refers to power output of solar panel (w); $\acute{\eta}_{PHV}\ (t)$ is defined as the efficiency of a solar panel (%); $A_{PHV}\ (t)$ represents the area of a single photovoltaic panels; and I_{PHV} (t) is the total radiation of solar energy.

6.3.4 Battery Energy Storage System

Incorporation of RES's to main grid (if the micro is grid connected) causes imbalance between the power supply and demand of micro grid system. This imbalance leads to huge frequency abnormalities on the system. Auxiliary services offer additional services needed for maintaining instantly and constantly the electrical power supply-demand balance (Al-Shetwi *et al.*, 2020) . One type of auxiliary services of battery energy storage is the adaptable reserve. The adaptable reserve is obtained by controlling the active electric power. Active power is modulated so as to maintain the frequency stability of the micro grid which is negatively impacted due to abrupt variations of generated power from the RES's (Al-Shetwi *et al.*, 2020). The rated capacity of energy storage system is affected various factors such as RES's (Mostafa *et al.*, 2020) , requirement of the reserve power, standby period, configuration of battery bank, temperature, life span of the battery, depth of discharge and so on (Mostafa *et al.*,2020). Following are the mathematical presentation of the charging and discharging strategies for battery energy storage.

The charging strategy of battery energy storage is expressed in equations (6.5) and (6.6) as follows:

$$E_{\mathrm{cpc}}\ (\mathrm{t}) = E_{cgg},\ \text{when } E_{PHV}\ (\mathrm{t}) + E_{HDT}\ (\mathrm{t}) + E_{GEB} + E_{GD}(t) - E_{DEM}(\mathrm{t}) \geq 0 \qquad (6.5)$$

The discharging strategy of battery energy storage is expressed in equations as follows:

$$\mathrm{E_{cpc}} = E_{dgg},\ \text{when } E_{PHV}\ (\mathrm{t}) + E_{HDT}\ (\mathrm{t}) + E_{GEB} + E_{GD}(t) - E_{DEM}(\mathrm{t}) < 0 \qquad (6.6)$$

At specific time, Battery energy storage system operates in either charging mode or discharging mode. Power of the battery in charging and discharging approaches is estimated as follows:

Charging approach

$$E_{cgg}(t) = \left(\frac{E_{HDT}\ (t) + E_{GEB}\ (t) + E_{GD}\ (t) - E_{DEM}(\mathrm{t})}{\acute{\eta}_{CVT}} + E_{PHV} \right) \times \Delta_t \times \acute{\eta}_t \qquad (6.7)$$

$$SOC\ (t) = \mathrm{SOC}\ (\mathrm{t}-1)(1-\sigma) + E_{cgg}(t) \qquad (6.8)$$

Discharging approach

$$E_{dgg}(t) = \left(\frac{-E_{HDT}(t) - E_{GEB}(t) - E_{GD}(t) + E_{DEM}(\mathrm{t})}{\acute{\eta}_{CVT}} - E_{PHV} \right) \times \Delta_t \times \acute{\eta}_t \qquad (6.9)$$

$$SOC\ (t) = SOC\ (t-1)(1-\sigma) + E_{cgg}(t) \qquad (6.10)$$

$SOC\ (t)$: Represents the state of charge of a battery at the specified time “ t ”

$SOC\ (t-1)$: Represents the state of charge of a battery at the specified time “t−1”

The lifespan of the battery energy storage system can be influenced by independent aspects such as throughput span of life ($q_{Lifecycle}$) and battery shelf life (F_{BAT}). The decision about selection of energy storage system can be reached by looking at the storage lifespan whether it is regulated either by time, throughput, or both. If storage characteristics show that the life span of the storage is constrained by throughput (q_{TPUT}), under this circumstance the battery bank need to be replaced if the accumulated throughput is equally balanced with its lifespan throughput. The lifespan of the battery of battery energy storage mechanism is calculated using the following equation (6.11) (Murty and Kumar, 2020).

$$\mathrm{F_{BAT}} = \begin{cases} \dfrac{\mathrm{N_{BAT}} \times \mathrm{q_{Lifecycle}}}{\mathrm{q_{TPUT}}}, & \text{if restricted by throughput} \\ \mathrm{F_{BAT\,f}} & \text{if restricted by time} \\ \mathrm{Min}\left(\dfrac{\mathrm{N_{BAT}} \times \mathrm{q_{Lifecycle}}}{\mathrm{q_{TPUT}}},\ \mathrm{F_{BAT,f}} \right) & \text{if restricted by both} \end{cases} \qquad (6.11)$$

The float life of battery energy storage system is defined as an entire time the storage system remains in operation before being replaced. During the creation of energy storage system, it is possible to restrict the existence either by time, throughput, or both (Murty and Kumar, 2020). The wearing cost battery storage mechanism is estimated using following equation (6.12):

$$C_{WCB} = \frac{C_{RCC,BAT}}{N_{BAT} \times q_{Life\ cycle \times \sqrt{\acute{\eta}rt}}} \qquad (6.12)$$

6.3.5 Converter

The industrial cattle farm requires alternating current (AC), while PVs provide direct current (DC). As a result, a converter is required to convert DC to AC and also conversely in the hybrid system. Equation (6.13) can be used to calculate the output power of the converter (Malamaki, 2020).

$$P_O = P_{IN} * \acute{\eta}_{INV} \quad (6.13)$$

Where,

$P_O =$ Output power of the converter

P_{INV} = Input power of the converter

$\acute{\eta}_{INV=}$ Efficiency of the inverter

6.4 TECHNICAL AND ECONOMIC DEFINITIONS

This sub-section of the research work presents technical and economic definitions including reliability, total NPC, levelized COE and capital recovery. Following are technical and economics definitions:

6.4.1 Insufficiency of Power Source Likelihood (IPSL)

The IPSL shows the likelihood of an energy imbalance (Shortage) occurring in the system within the specified time period. It is calculated by dividing the overall energy deficit by the total load demand during that time period. Its value is specified as equation (6.14) (Fares, Fathi et al., 2022)

$$\mathrm{IPSL} = \frac{\sum_{t}^{T} \mathrm{IPS\ (t)}}{\sum_{t}^{T} \mathrm{L_T\ \ (t)}} \quad (6.14)$$

, where IPS is the insufficiency in power supply, $\mathrm{L_T}$ is the total electrical load and T is a period of time for a year which is equivalent to 8760 hours. If IPSL equals to zero it implies that hybrid micro grid system produces sufficient power for the load and if the IPSL is one it means that the system is incapable of satisfying the load. IPS is given in equation (6.15) (Mudgal *et al.*, 2019):

$$IPS = P_L - (P_{ghybrid} + SOC_t - SOC_{mini}), \quad (6.15)$$

Where, $P_{ghybrid}$is the total power generated from hybrid micro grid system, SOC_t is the state of charge of the battery at time t, and SOC_{mini} is the minimum state of charge of the battery.

6.4.2 Total Net Present Cost (NPC)

Total NPC expresses lifetime expenditures of the HRESS. It consists of whole disbursement and earnings which occur in the lifetime of the system. It consists of a number of expenses such as investment cost of the system apparatuses, prices for replacement incurred during the system operation, fuel costs, and the expenses for operation and maintenance of the system. The complete net present cost is simply defined in equation (6.16) as follows (Fares *et al.*, 2022):

$$\text{Total NPC} = \text{PC} + \text{OMC} + \text{RC} + \text{FLC} \tag{6.16}$$

where, PC is the whole investment price, OMC refers to the operation and maintenance price, RC is the replacement price, and FLC is defined as fuel price.

6.4.3 Cost for Energy Consumption per Unit

The cost for energy consumption per unit is an analogous term to the levelized cost of energy (LCOE). LCOE is described as the average price per unit of generated electricity ($/kWh). It can be expressed as follows in equation (6.17) (Jahangir *et al.*, 2022)

$$LCOE\left(\frac{\$}{kWh}\right) = \frac{\text{Total NPC} \times \text{CRF}}{\sum_t^T \mathrm{G_T}} \tag{6.17}$$

CRF is the investment retrieval factor and is mathematically expressed as follows in equation (6.18) (Yimen, Tchotang et al. 2020) (Fares *et al.*, 2022):

$$CRF = \frac{R(1+R)^K}{(1+R)^K - 1} \tag{6.18}$$

Where, R denotes the interest rate (%), and K (time in years) is lifetime of the system.

6.4.4 Salvage Charge

Certain different components may keep on working after the project is completed. In this situation, the components of the system will be sold. Salvage costs (SV) are determined by the project's and product's lifespan and can be calculated as follows in equation (6.19) (Jahangir et al., 2022):

$$SV = C_{REP} * \frac{T_{PROJ} - T_{COMP} \int \frac{T_{PROJ}}{T_{COMP}}}{T_{COMP}} \tag{6.19}$$

Where, C_{REP} stands for replacement cost (\$),T_{COMP} represents component lifetime (number of years), and T_{PROJ} refers to the project life time.

6.4.5 Operating Charge

During its operational life, each component incurs maintenance costs. The following expression can be used to compute the operating cost (6.20) ((Jahangir *et al*., 2022):

$$\boldsymbol{c_{OPR}} = \boldsymbol{C_{TOT.ANN}} - \boldsymbol{C_{CAP.ANN}} \tag{6.20}$$

Where,

$\boldsymbol{c_{OPR}}$ = Operating charge

$\boldsymbol{C_{TOT.ANN}}$ = Total annualized cost (in US dollars per year)

$\boldsymbol{C_{CAP.ANN}}$ = Total yearly capital cost (in US dollars per year)

6.5 TECHNICAL, ECONOMIC AND LOCATION DATA

This section presents the specifications and costs of the components in the proposed hybrid. The off-grid HRESS is constructed by components with dissimilar features and expenses. The components of the system are such as solar modules, biogas powered generator, small hydro, battery bank, Converter. Tables 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7 and 6.8 represent input parameters of micro hydro energy source, input parameters of solar PV generator, Input parameters of biogas generator, input parameters of battery, input parameters of converter, :input parameters of DG (Comparative analysis against off-grid HRESS, input parameters for BGE (Comparative analysis against off-grid HRESS), and project site respectively. Following are the inputs technical standards, capital, replacement and operation & maintenance costs of the components and details of project site:

Table 6.1: Input parameters of micro hydro energy source

Parameter	Magnitude/Value
Capital charge (\$)	5500
Replacement cost (\$/year)	0.0
Operation and maintenance cost (O&M), (\$/year)	10
Lifespan of service (years)	75
Pipe loss (%)	20
Available head (m)	13
Design flow rate (L/s)	890
Minimum flow ratio	65
Maximum flow ratio	115

Efficiency ή	75

Table 6.2: Input parameters of solar PV generator

Parameter	Magnitude/Value
Capital charge ($)	250
Replacement cost ($/year)	0
Operation and maintenance cost (O&M), ($/year)	0
Lifespan of service (years)	25
Derating factor	80

Table 6.3: Input parameters of biogas generator

Parameter	Magnitude/Value
Capital charge ($)	300
Replacement cost ($/year)	225
Operation and maintenance cost (O&M), ($/year)	0.010
Lifespan of service (Hours)	20000
Minimum load ratio	50

Table 6.4: Input parameters of battery

Parameter	Magnitude/Value
Capital charge ($)	120
Replacement cost ($/year)	120
Operation and maintenance cost (O&M), ($/year)	10
Lifespan of service (years)	15

Table 6.5: Input parameters of converter

Parameter	Magnitude/Value
Capital charge ($)	170
Replacement cost ($/year)	170
Operation and maintenance cost (O&M), ($/year)	10
Lifespan of service (years)	15
Efficiency ή (%)	95

Table 6.6: Input parameters of DG (Comparative analysis against off-grid HRESS)

Parameter	Magnitude/Value
Capital charge ($)	16000
Replacement cost ($/year)	16000
Operation and maintenance cost (O&M), ($/year)	0.030
Fuel price ($/Litre)	1

Table 6.7: Input parameters for BGE (Comparative analysis against off-grid HRESS)

Parameter	Magnitude/Value
Price of grid extension per km ($)	10 000
Price of O&M), ($/year)	7500
Grid power price per unit	0.15

Table 6.8: Project site

Parameter	Magnitude/Value
Project lifetime (Years)	25
Inflation (%)	3.04
Discount rate (%)	7.0

6.6 SENSITIVITY ANALYSIS

In this study, sensitivity of the proposed off-grid HRESS in has also been investigated. The sensitivity investigation has been implemented by variation of cost of the components, fuel consumption, price of battery and energy cost against the additional reserve(Jahangir, Montazeri et al. 2022): .

6.7 SYSTEM CONTROL STRATEGIES

In this section of chapter 6, CC (Cycle charging) and LF (Load following) control strategies are presented as follows:

6.7.1 CC Control Strategy

The CC control strategy is a dispatch approach that requires generators to run at full capacity every time they start. The generated electricity is subsequently used to power primary and deferred loads as well as charge the storage systems (Jahangir, Montazeri et al. 2022).

6.7.2 LF Control Strategy

In contrary to the CC technique, LF control strategies use the generator to give electricity to the principal load whenever it is required. In order to put it another way, renewable energy source will power both the postponed load and the batteries (Jahangir *et al.*, 2022).

6.8 RESULTS AND DISCUSSION

The proposed system consists of small hydro energy source, biogas powered generator, solar energy source including the battery bank for storing energy (micro-hydro-biogas- Solar PV- battery bank) is optimized alongside with the same system excluding batteries (micro-hydro-biogas- solar PV), and standalone diesel powered generator. This type of hybrid system is advocated owing to the availability of power sources, electrical load profile, amenities, reliability, economic and ecological benefits. These patterns of energy systems are optimized using HOMER pro software. Optimal configurations of the energy system are obtained at the least total NPC with its corresponding LCOE. Comparative study is made among the three optimal configurations in terms of the accrued NPC, LCOE, and greenhouse gas (GHG) emissions particularly the magnitude of CO_2 emissions, and breakeven of grid extension distance . Sensitivity analysis is carried out to examine the impacts of the variation when the optimized energy system is subjected under different and variable conditions.

6.8.1 Optimization Results

It is a matter of fact that the HRESS can be operate on grid connected and/or off-grid modes. The benefits of this mode include the surplus clean energy supplied (selling) to the grid power network and supporting grid capacity. When operating in off-grid mode, renewable power source is more expensive than grid electricity and the only revenue source is salvage, the system's NPC and LCOE will be higher than when running on-grid. Here, the optimal off-grid HRESS is anticipated to supply power to the selected area of study

This is the most cost-effective off-grid HRESS in respect of LCOE and NPC, and the optimal dispatch mode is CC control strategy. The SPV panel has the largest capital cost, as seen. There are no replacement expenditures because the solar panels are compatible with the project's life. The biogas generator, on the other hand, has the highest replacement cost. The generation of power from biomass, hydro, and solar panels is dependent on the availability of biomass, water, and solar radiation, in that order. As a result, power from these three resources is not continuous. The battery is integrated into off-grid HRESS to ensure the system's dependability. Biogas has the highest cost, after the biogas, and after the biogas generator cost, the majority of the capital expenditure is spent on batteries followed by Solar PV. Actually, hydro energy source is less volatile than solar PV system and also its lifetime is assumed to be 75 years (3 times of solar panel’s lifecycle or project lifecycle). In order to gain maximum reliability with the inclusion of battery bank, hydro power has highest penetration of all renewable energy sources constituting the off-grid HERSS.

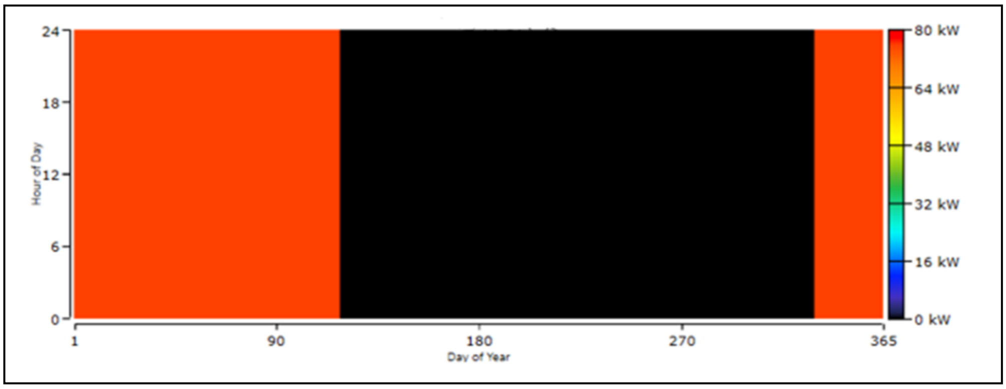


Figure 6.2. Power output of hydro power source in the system

. As it is indicated in the Table 6.11, penetration levels for hydro and SPV energy sources are 470 % and 90.1 % respectively. Efficiency for biogas generator is 31.0% Figure 6.2 indicates power output of hydro power source in the system.

Table 6.9: Economic results of optimal off-grid HRESS

Component	Capital fee ($)	Replacement fee ($)	O & M fee ($/Year)	Fuel fee ($)	Salvage ($)	Total ($)
Hydro	5500.00	0.00	158.84	0.00	0.00	5658.84
Batteries	5 760.00	10 970.38	7624.46	0.00	28.60	24 326.24
Biogas gen	3000.00	2532.91	30243.70	253.94	543.41	35487.15
Solar PV	7500.00	0.00	0.00	0.00	0.00	7500.00
Converter	3 400.00	1931.12	0.00	0.00	441.48	4 889.64
HRESS	25 160.00	15 434.41	38027.0	254.94	1013.48	77 861.88

Table: 6. 10: Optimization and comparative analysis results of HRESS and DG

System	Bio (kW)	PV (kW)	Hydro (kW)	Battery (QTY)	Converter (kW)	Dispatch (CC/LF)	RF	NPC ($)	LCOE ($/kWh)
HRESS	10	30	85.1	48	20	CC	100	77861.88	0.08117
DG	--	--	--	--	--	CC	0	1824076.00	1.90

Note: Nominal capacity for DG = 12 kW

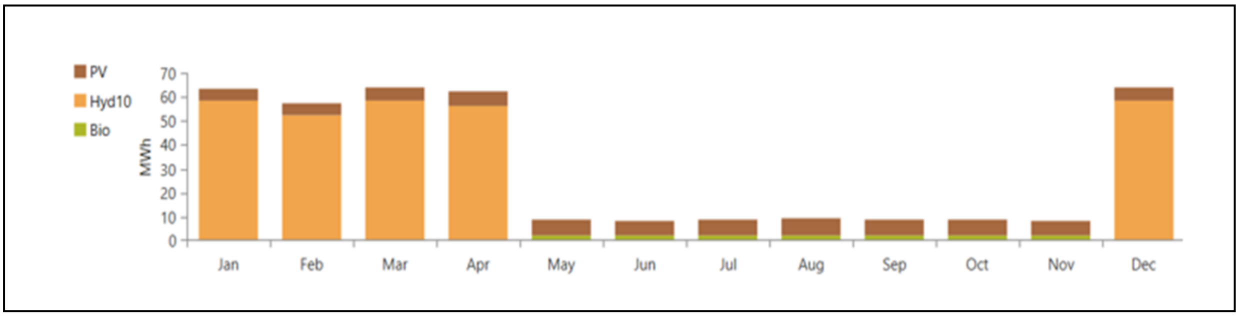


Figure 6.3. Monthly electricity production of each device in off-grid HRESS

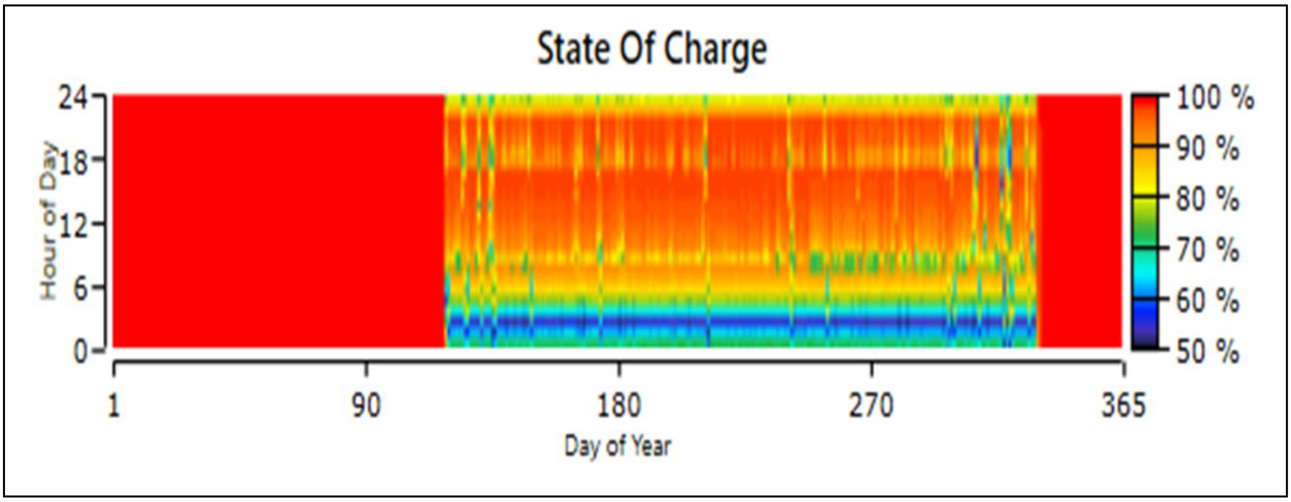


Figure 6.4. Annual state of the charge of battery ESS

Table 6.10: Some specifications of electricity generation of optimal off-grid HRESS

Parameter	Renewable energy source		
	Hydro	Solar PV	Biogas gen
Nominal capacity (kW)	85.1	30	10
Level of penetration (%)	470	90.1	--
Capacity factor (%)	38.1	20.7	19.5
Electric production (kWh/year)	283 818	54 412	17 097
Hours of operation	3624	4448	1904
Fuel usage (tons/year)	NA	NA	2.11
Fuel input (kWh/year)	NA	NA	55 151
Constant generation cost ($/hour)	NA	NA	1.11
LCOE ($/kWh)	0.00126	0.00868	0.000886

The system has the lowest NPC in comparison both solar and biomass energy sources. Figure 6.3indicates the monthly electricity production of each device in off-grid HRESS. Table indicates optimization and comparative analysis results of HRESS and DG. Table 6.9 Economic results of optimal off- grid HRESS whereas Table 6.10 presents optimization and comparative analysis results of HRESS and DG. Some specifications of electricity generation of optimal off-grid HRESS are presented in Table 6.11.

6.8.2 Sensitivity Analysis Results

In this portion of the research work, evaluation of the sensitivity has been conducted to examine the influence of essential variables on the operation of energy system. The essential parameters in consideration for analysing the sensitivity are solar radiation, derating factor, biomass fuel price, and water flow rate and increase in energy consumption.

6.8.2.1 Solar radiation

The intensity and efficiency of solar radiation and solar modules play a major part in the bringing in the solar energy in the HRESS. The power output from the array of PV panels rises up when solar energy radiation increases and opposite of it is also true. Therefore, the variation of this radiation influences considerably the operation of the energy system. The average of annual solar radiation of the selected area of study is 6.11 kWh/m^2/day. The annual solar radiation has been varied between 4 to 8 kWh/m^2/day. The variation of solar radiation in the aforementioned range, the NPC and emissions of CO_2 declined from $ 77, 861. 88 to $ 73, 968.77 and from 9. 29 kg/year to7. 09 kg/ year, respectively. The decrements of NPC and CO_2 happened since the intensification of solar radiation augmented the power output of PV; thus, the operating hours of generator and fuel consumption are reduced.

6.8.2. 2 Derating factor

Derating factor is one of the important input variables related with solar energy source. Derating factor may vary from one place to another within the country. During the optimization derating factor was assumed to be 80%. In this study, derating factor has been varied using values 65%, 75%, 85% and 95%. The variation of derating factor in the aforesaid range, the NPC and emissions of CO_2 declined from \$ 77, 861. 88 to \$ 77, 849.784 and from 9. 29 kg/year to7. 073 kg/ year, respectively. Increased derating factor reduces the operating and initial costs of the system.

6. 8.2.3 Design water flow rate

The magnitude of the water flow rate (litres/second), water head (m) and the efficiency of water turbine influences the energy production of the system. The energy output of the hydro energy power increases when the design water flow rate elevates and vice versa. Therefore, the variability of design water flow rate effect substantially the performance of the system. In the optimization of the proposed system, assumed design water flow rate is 890 litres/ second. The variation of the design flow rate has been varied from 650 L/s, 850 L/s, 950 l/s, and 1050 l/s. The increase in flow rate increases the power capacity of hydro. The variability of the design water rate in the range as described above, NPC and emissions of CO2 reduced from 77, 861. 88 to and 73, 968. 86 from 9. 29 kg/year to 6. 55 kg/ year, respectively. The diminutions/additions of NPC and CO_2 occur due to the increase of generated power output demanding for more operating hours of biogas generator and its fuel consumption, increased energy production from water turbine and solar PV panels.

6.8.2.4 Biomass/ biogas fuel price

Biomass/biogas fuel price may vary from one place to another within the country and may also differ from time to time depending on the available market of same locality. Assumed price of biomass/ biogas fuel in the area of study is approximated to be \$ 0.31/ton. The investigation of the impact of biomass/biogas price variability on the operation of the system, the sensitivity evaluation has been implemented by varying the biomass/ biogas fuel cost between \$ 0.25/ton to 8/ton. In fact, the increase in biomass/biogas fuel expense from the above mentioned range, the CO_2 discharges reduced from 9. 29 kg/year to 6. 55 kg/year whereas NPC elevated from $ 77, 861. 88 to $ 106, 300.4. Basically, such kind of findings which are related to the increase of biomass/ biogas fuel price may discourage the utilization of biomass/ biogas powered generator (Increased operating cost). It is an implication that the working hours of the biogas generator get reduced (Run for a limited time to serve cost).

6.8.2.5 Increase in energy consumption

Energy system should produce power output which matches with energy requirement. Energy consumption varies frequently at different times. If the energy consumption rises, electricity generation should also rise imperatively. In this specific study, a number of consumptions (155, 165, 175, 160, 185, and 195 kWh/day) are considered for the investigation of their influence on the system operation. It has been observed that NPC and CO_2 of the optimized system has increased by 23 % and 53 % respectively, when consumed energy has risen from 155 kWh/day to 195 kWh/day. The major reason for such augmentations of NPC and CO_2 is due to the rise of needed power capacity of different subsystems for increasing the energy generations of energy system.

6.9 COMPARATIVE ANALYSIS RESULTS OF CARBON EMISSIONS

The emission details of the scenarios which are related to the case study are given in Table 6.10. As can be observed, there are substantial reduced carbon emissions in off-grid HRESS in comparison with DG. Generally, proposed system can reduce the carbon emissions in the range of 99 to 100%. For instance, DG can produce carbon dioxide (CO_2) around 52680 kg/year while its counterpart off-grid HRESS can produces same kind of emissions 9.29 kg/yr. Table 6.12 indicates emissions details of the scenarios which are related to the case study.

Table 6.12: Emissions details of the scenarios which are related to the case study

Scenario	CO2(kg/Yr)	CO(kg/Yr)	UNHC (kg/Yr)	PM (kg/Yr)	SO2(kg/Yr)	NOX (kg/Yr)	RF
DG	52680	332	14.5	2.01	129	312	0
HRESS	9.29	0.103	0	0	0	0.0645	100
RCE	52670.71	331.897	14.5	2.01	129	311.9355	--
RCE (%)	99.98	99.97	100	100	100	99.88	--

Note: RCE = Reduction in carbon emissions, UNHC = Unburned hydrocarbons, PM = Particulate matter

6.10 BREAKEVEN GRID EXTENSION (BGE) DISTANCE

This part of this chapter gives the presentation of compares economic distance limits of proposed HRESS with batteries, HRESS without batteries, and DG. Table 6.13 indicates the economic distance limits (EDL) of proposed HRESS with batteries, HRESS without batteries, and distributed DG.

Table 6.13: Economic distance limits of proposed HRESS with batteries, HRESS without batteries, and DG

BGE	Scenarios		
	HRESS with batteries	HRESS without batteries	DG
Economic distance limit (km)	0.78	0.28	3.58

6. 11 CONCLUSIONS

The proposed off-hybrid energy system has been optimized to produce alternating current (AC) electricity owing to the flexibility in accessibility of electrical energy to the energy storage appliances. To design a plan for rural electrification and for lowering the carbon emissions in big rural livestock sites, HRESS's are modelled and analyzed. Simboya village, Tanzania acts as a case study in this regard. When modelling hybrid renewable scenarios, all renewable potentials (here solar and hydro energy sources) in the case study, as well as on-site biomass sources are taken into account. In this research work, proposed hybrid solar -hydro-biogas-battery bank system for electrical supply to the aforementioned village. In addition, another off-grid HRESS without battery bank has been compared with the proposed hybrid solar-hydro-biogas-battery bank system in terms of BGE. The following are the investigation's most noteworthy findings of the proposed off-grid HRESS:

- With an NPC of $ 77 861. 88 and a LCOE of 0.08117 $/kWh, the proposed hybrid solar-hydro-biogas-battery bank configuration is determined to be the best system.
- In fact, as the cost of biomass/biogas fuel increased from the previously specified range, CO_2 emissions decreased from 9. 29 kg/year to 6. 55 kg/year, while NPC increased from $77, 861. 88 to $106, 300.4. In general, findings relating to an increase in the price of biomass/biogas fuel may inhibit the use of biomass/biogas powered generators (Increased operating cost). It implies that the biogas generator's operating hours will be reduced (Running time need to be restricted to save money).
- When the used energy was increased from155 kWh/day to 195 kWh/day, the NPC and carbon dioxide of the optimised system increased by 23% and 53%, respectively. The primary reason for such NPC and CO_2 augmentations is the increase in required power capacity of various subsystems for boosting energy generation of the energy system.

- The NPC and CO_2 emissions fell from \$77, 861. 88 to \$77, 849.784 and 9. 29 Kg/year to 7. 073 Kg/year, respectively. A higher derating factor lowers the system's running and starting costs.
- It was determined that using the renewable based proposed configuration for electric power to Simboya village in Tanzania is capable of reducing carbon emissions in the range of 99 % to 100 %. For instance, the proposed off-grid HRESS to generate power saves 52670.71kg (99.88%) of CO_2 per year as compared to the equivalent capacity of DG.
- The economic distance limits for, HRESS with batteries, HRESS without batteries, and DG are 0.78 km, 0.28 km, and 3.58 km respectively. Beyond these limits grid extension is financially impractical.

6. 12 FUTURE RESEARCH WORK

The current study involves the hybrid of biogas, hydro and solar energy sources integrated with the bank of lead acid batteries for the Tanzanian environment and other similar parts in the worldwide. In the future research such off-grid HRESS can be enhanced by integrating with other sources such as grid and optimized by advanced AI techniques.

CHAPTER 7

DEVELOPMENT AND IMPLEMENTATION OF INTELLIGENT TECHNIQUE FOR MODELLING AND SIZING OF RES BASED MICRO GRID SYSTEM

7.0 GENERAL

Energy is one of the most important infrastructures required for a prosperous human life. Electricity raises a country's level of lifestyle and economic progress. Electricity promotes agricultural, industrial, transportation, tourism, and mining development (Zhang *et al.* 2019). The majority of countries throughout the world build fossil-fuel-powered power plants to meet energy requirements through on- and off-grid energy systems. Hydro, natural gas, and liquid fuels are the primary sources of power (Jacob, 2017). For at least the last two decades, hydro energy has dominated the Tanzanian power sector (Mdee *et al.*, 2018; Sridharan *et al.*, 2019). The combined capacity of HPP (Hydro Power Pants) was 561.84 MW. Previously, the capacities of off-grid NGPP's and off-grid DG power plants (DPP) were 25.25 Megawatts and 28.682 Megawatt, respectively. However, the expansion of NGPP (Natural Gas Power Plants) with an anticipated capacity of 495.44MW outweighed the quantity of hydro power (Mdee et al., 2018). The overall generation of electricity is estimated to be 1450 MW, with NGPP, HPP, and NGPP accounting for 652.5 MW, 609 MW, and 188.5 MW, respectively (Bishoge *et al*., 2019). The use of fossil fuels in electricity production for grid extension is both depletive and costly. These fossil fuels are also harmful to the ecosystem, creating pollution, global warming, and a variety of other disorders (Kalair *et al*., 2021). The long gestation period of installing state electric grid, as well as the power quality concerns connected with power distribution from remote generating areas, causes delays in obtaining electricity in off-grid locales (Muh and Tabet, 2019). Rural electrification is lesser than of urban centers (Mdee *et al*.,2018). To reduce power deficits in rural regions, a decentralized technique using diesel-powered generators has been employed to generate electricity (Zakaria, 2016; Bishoge *et al*., 2019). Diesel generators, on the other hand, are unsuitable due to their high fuel costs and damaging carbon dioxide emissions (Zakaria, 2016; Chauhan and Saini, 2016). The country has a large potential for renewable energy resources that can help to overcome energy shortages in rural areas. Biomass, solar, tidal, wave, geothermal wind and hydro are among these resources (Melkior *et al*., 2018; Bishoge *et al.* 2019). These renewable energy sources may have made a significant contribution to addressing the nation's power crisis, particularly in telecommunications, transportation, industries, mining, agriculture, tourism, etc.

However, the advancement of these non-conventional energy resources in Tanzania is hampered by a number of obstacles, including a lack of human capital and training, high investment costs, limited awareness, minimal and limited research and innovation, a centralized approach (dominance) pertaining to the institutional framework, and a preference for centralized electricity from the national grid (TANESCO), which leads to a low adoption of decentralized power schemes (Bishoge, 2019). Biomass, in the form of firewood or charcoal, is a non-conventional energy resource that is widely used worldwide, particularly in developing nations, for food preparation and warmth. Biomass is a renewable power source obtained from organic material obtained from animals and plants (Anyogu *et al*., 2021). It is composed of sun-stored energy. When biomass is burned, its energy is converted into heat. Photosynthesis, which occurs as trees and plants grow, uses energy from the sun to convert CO2 into carbohydrates such as sugars, starches, and cellulose (Anyogu *et al.*, 2021). Carbohydrates are organic substances that occur naturally in biomass. When trees (plants) die, the energy held in carbohydrates is released via the breakdown process, which emits CO2 into the atmosphere. It is a renewable power source since the addition of new plants and trees replaces the supply. Renewable energy is beneficial because it fosters financial stability, energy security, and environmental sustainability (Anyogu *et al.*, 2021). The shift from petroleum-based commodities (i.e., fossil fuels) to biomass-derived substances promotes the production of long-term carbon-based consumables. Some of the benefits of biomass include: (i) Bioenergy is a renewable power source obtained from organic substances such as animals or plants waste, and it is never depleted. Trees can be replaced by planting (ii) while burning biomass generates CO_2; it also accumulates CO_2 for its own development, making it healthier than fossil fuels. CO_2 releases from fossil fuels, on the other hand, are released into the atmosphere and are harmful to the eco-system (iii) bioenergy is a cheap and readily accessible source of energy. Bioenergy can also be a long-term, sustainable energy source if woods are replenished (iv) reduces the need for rubbish dumps (landfills). Biomass converts ecologically dangerous waste into something valuable by burning it for energy (v) less reliance on fossil fuels. The use of biomass as a fuel source reduces our reliance on conventional energy sources, which is beneficial for the planet and more cost effective (Anyogu *et al.*, 2021). One of the disadvantages of using biomass is the high investment cost. A biomass boiler has a greater upfront outlay than a normal gas or oil stove (ii) requires a lot of area. Its boiler systems are often larger than those of oil or gas burners and require a fuel storage area (iii) harmful to the environment. Methane gas outputs are detrimental to people and nature.

((iv) it may result in deforestation; ((v) it may provide inefficient energy. Biomass fuel performance is weaker to that of carbon fuels (Anyogu *et al.* 2021). Biodiesel derived from biomass, i.e. ethanol, is inefficient when compared to fossil fuels. It has the potential to cause extermination, loss of habitat, displacement, and other detrimental effects on biodiversity (Anyogu *et al*., 2021). The following are some of the disadvantages of biomass utilization: Non-renewable energy sources are high-quality commodities that can be successfully incorporated into a wide range of existing power conversion systems. Because of its higher oxygen content, biomass has lower energy content. Furthermore, because bioenergy is a very light and dense substance, the amount of biomass to be handled may be substantial, posing storage and logistical difficulties (Costa *et al*., 2020).

The direct use of biomass-fired technology involves various technological hurdles, such as combustor fouling and degradation caused by the alkalis in biomass wastes. Slagging and fouling obstruct heat transfer at combustor substrates and cause erosion and corrosion, limiting equipment lifetime (Costa *et al.*, 2020).

The estimated annual energy yielded from lignocellulosic materials accounts for about 10% of global energy demand (Qaisar *et al.*, 2021). Agricultural and forest waste alone contributed 30 EJ, which is a substantial amount, to the yearly energy use of 4500 EJ (Qaisar *et al.*, 2021). In Europe, biomass availability potential ranges from 615 to 728 million tonnes. Agricultural wastes amount to around 12.8 mil. tonnes per year in Italy. Herbaceous crops, for instance, sunflower stalks, straw, and maize stalks) cultivated predominantly in the North can produce 9.3 million tonnes, whereas arboreal crops, for instance, olive and fruit plants and vines produced primarily in the South may produce 3.5 mil. tonnes (Costa *et al.*, 2020).

Tanzania has 33 million hectares wood fields and backwoods, according to United Nations food And agribusiness Organization's Global Forests Resources Assessment study, however it loses around 400,000 hectares of timberland every year (Qaisar *et al.*, 2021). Around 75% of collected wood isn't represented in government financial plan frameworks, bringing about income misfortune. The typical family consumes roughly 47 kg of charcoal every month. Roughly 2500 million individuals overall depend on kindling for cooking and warming (Bishoge *et al.*, 2019). In the SSA district, including Tanzania, the populace utilizes roughly

85% of all kindling is taken from forests as energy or charcoal for cooking and warming (Bishoge *et al.*, 2019). For example, starting around 2018, the populace was 56.32 million individuals. Just 35.6 percent of the general populace has power access; this relates to very nearly 36 million Tanzanians who don't approach power. Biomass (for example kindling, charcoal, etc.) is as yet utilized as a wellspring of energy by 80% of Tanzanians (Bishoge *et al.,* 2019). Whether consumed inside or outside, the smoke made is a poison associated with negative wellbeing results; especially respiratory problems can definitely influence youngsters and ladies (Bishoge *et al.*, 2019). The people who live in Tanzania's cooler southern good country locales as often as possible cook inside, expanding their openness to smoke contamination. No matter what the high likely biomass in the country, there are just three power plants fuelled by biomass having essentially introduced limit of 5.1 MW up to 18 MW, while the agro-business based power plants create around 58 MW of their own power [10] [14] (Qaisar et al., 2021) ; Bishoge *et al.*, 2019.

Biofuels, basically bio-oil, bio-ethanol, bio-oil, and gas, and manufactured substances, can be all around created utilizing lignocellulosic resources (Qaisar *et al*., 2021). For lignocellulosic biomass change, different change processes are open that take thermo-substance, warm, and natural courses (Qaisar *et al.*, 2021). The start of biomass for power and hotness age is suggested as warm change. The most well-known approach to changing over biomass using unbelievable hotness and engineered compounds is named as thermo-substance change (Qaisar *et al*., 2021). It is furthermore described into procedures like gasification and pyrolysis. These strategies produce bio-oil and fuel, as well as unambiguous fabricated materials. Bio change is normal for changing biomass into biofuels using smaller than usual animals. Its fundamental thing is bio-ethanol, despite the way that it similarly delivers bio-butanol, biogas (methane), and little fabricated materials (Qaisar *et al.*, 2021). Preceding bioconversion, pre-treatment is vital for confined the components of biomass for ideal maturing (Qaisar *et al.*, 2021). Anyway, including feedstock requires a basic interest in power, hotness, and work all through the change cycle. The focal point of the issue is the over the top pre-treatment stage, which raises the entire cost of bioconversion. Substance and physicochemical pre-medications are by and by the best. They are, regardless, hazardous to the environment and produce unsafe side-results like furfural. Subsequently, innocuous to the biological system natural pre-treatment strategies are used sometimes, yet with diminished fermentable sugar yields (Qaisar *et al*., 2021).

Incorporated bio treatment facilities increment the utilization and utilization of biomass to create common energy by blending key transformation, split-up, and downstream improvement processes. It is a need for cultivating maintainable energy in a savvy way. Nonetheless, carrying out them on a business premise is troublesome. Late exploration has zeroed in on lignin science and valorization, cost-cutting measures, the manageability of pre-treatment methodology, the benefits and inconveniences of different pre-treatment strategies, and the progress cycles of lignocellulosic biomass (Qaisar *et al.*, 2021).

The change of lignocellulosic biomass into bioenergy is subject to different cycles, containing (i) warm change by consuming, (ii) thermochemical change through both gasification and pyrolysis (iii) physiological (miniature natural) change including the utilization of biocatalyst (Qaisar *et al.*, 2021).

(A) Thermal conversion: High-temperature direct combustion of lignocellulosic biomass produces thermal energy as well as ash particles. The thermal energy obtained can be used to generate electricity and power. On a commercial basis, it is a low-cost method that has been thoroughly developed. However, it is not an environmentally favourable process because ash particles cause significant pollution (Qaisar *et al.*, 2021). Whole process is fully described as follows: Direct combustion of biomass at hot temperatures (800–1600 C) produces thermal energy. When the fuel combines with oxygen, heat energy is produced, as well as flue gas containing CO2 and water. The intensity of the heat flame can surpass 1650 C and is determined by the moisture contained in the biomass and heating value of the energy, the structure of the furnace, as well as the fuel-to-air ratio (Qaisar *et al.*, 2021). Because of their increased efficiency, biomass pellets are extensively used in commercial combustion in European countries. For this technique, biomass with moisture contained in biomass below 50 % is recommended (Qaisar *et al.*, 2021). Combustion is carried out on a variety of scales utilizing a variety of equipment such as stoves, boiler, furnaces, turbo generators, and turbines. It is required for turning the chemical energy in biomass into mechanical energy. The combustion of fossil fuels results in massive emissions of CO2, NOx, PM (particulate matter), and cinders. These discharges to the environment represent significant greenhouse gasses risks (Qaisar *et al.*, 2021).

(B) Thermochemical conversion: The conversion of biomass into liquid or gas, which is then upgraded into biofuel, a physical catalyst or heat, is used. This method necessitates a high level of energy consumption. The chemicals utilized are frequently costly, and as a consequence, inhibitors are produced. The cost of cleaning up emissions and pollutants is inextricably linked to the total price of the process (Qaisar *et al.*, 2021).

Gasification: is a thermo-chemical activity that combines the interaction of biomass in the presence of air, oxygen or steam to generate a combination of gases, including hydrogen (H2) methane (CH4), carbon monoxide (CO), carbon dioxide (CO2), nitrogen (N2), and hydrocarbons called as syngas, producer gas, or synthetic gas, the quantities of which vary (Qaisar *et al.*, 2021; Aslam *et al.*, 2021). The primary goal of the process of gasification is to maximize the yield of vapours while minimizing the production of un-reacted char and hydrolyzable hydrocarbons. There are basically three significant types of gasification processes: fixed bed fluidized bed as well as entertained flow (Qaisar *et al.*, 2021). Gasification generates heat that can be used by kilns or boilers. Because unattractive compounds such as tars are destroyed during gas combustion, the syngas used is barely cleansed. If the tar is not overwhelmed and the majority of the particulate matter is removed from the gasifier, syngas can also be used in combustion engines (Qaisar *et al.*, 2021; Aslam *et al.*, 2021). Gas turbines encourage high-efficiency integrated gasification-combined cycle power, while good gas cleaning is required. Syngas is produced in a gasifier either explicitly or implicitly supplying temperatures of 600 º C to 1000 ºC to the gasifier (Qaisar *et al.*, 2021). A successful gasification reaction has interval of time of around 3 to 4 seconds. Syngas is essential for the production of a wide range of chemicals and fuels such as organic acids, alcohol, esters and hydrocarbon fuels (Qaisar *et al.*, 2021). Gasification has a broad range of applications being required for hydrogen production, thermally powered generation, and the synthesizing of chemicals and fuels (Qaisar *et al.*, 2021). This promotes energy industries based on gasification that generate an assortment of various chemicals and energy. Utilization of micro-turbine driven biomass energy systems (syngas) and CHP (combined heat and power) gasification based systems are examples of thermally powered generation (Costa *et al.*, 2020).

Pyrolysis: Pyrolysis is defined as a thermo-chemical process that can occur as an early step to combustion processes or as a standalone process for biofuel production. Pyrolysis is the degradation of lignocellulosic materials into an aromatic and carbon-rich solid in the lack of oxygen at temperatures starting from 300 – 900 ºC. This procedure yields bio-char (solid type), bio-oil (liquid type), and flue gases (gaseous condition) (Qaisar *et al.*, 2021).

(C) Bioconversion: is the process of converting biomass into biofuel by employing bio-catalysts either directly or indirectly as part of a prior pre-treatment step (Aslam *et al*., 2021; Qaisar *et al*., 2021). Complex carbohydrates are broken down into intermediate sugars, which are then fermented to make biofuels like ethanol. Bio-control agents, such as enzymes or a cluster of microorganisms, enable this conversion. It is an extremely selective, high-conversion-efficiency method. Unfortunately, this procedure takes more time plus an extremely high pre-treatment cost, indicating the process's infeasibility (Qaisar *et al*., 2021).

DMC (direct microbial conversion) or CBP (consolidated bio-processing) is a method of producing value-added products by combining enzymatic hydrolysis and fermentation using a cluster or a sole organism. Without any pre-treatment, lignocellulosic biomass is transformed straight into biofuels (Qaisar *et al*., 2021).

Indirect biological conversion: Lignocellulosic biomass is first decomposed into fermentable sugars, which are then fermented into biofuels (Qaisar *et al.*, 2021).

Geothermal energy is the energy (in form of heat) that is produced and retained in the Earth. It is both clean and sustainable, and it can be found in the bedrock and fluids underneath the Earth's crust. It is available from low ground to several miles beneath the surface, and even deeper to the exceptionally hot molten rock known as magma (Anyogu *et al*., 2021). Some merits of geothermal energy are such as (i) It is ecologically friendly: A geothermal power station has a very low carbon footprint. The CO_2 emitted by geothermal power stations is one-eighth of that emitted by an equivalent coal power station (ii) Stable resource: The plant's power output can be forecast and is not subjected to the equal low energy variations as solar or wind (iii) A renewable resource: Geothermal reservoirs are refilled naturally (iv) No propellant involved: After construction, no mine or logistic activity is required (v) Minimal land footprint: Its plant installation requires a small amount of land (vi) Economic criteria: Some places are cost-competitive (vii) Accessibility: Most places have some amount of geothermal power available (Anyogu *et al.*, 2021).

Some demerits of geothermal are such as (i) Production of hazardous emissions: Greenhouse gases (sulphur, CO2, silica) are commonly found near plants. Toxic heavy metals such as mercury, arsenic, and boron may be present in the reservoirs (ii) Geographical restrictions: Suitable geothermal reserves are few. Prime locations are frequently located distant from major population centres (iii) Pump powering costs: Geothermal heat pumps require a power source (iv) Expensive electricity: Total costs for a megawatt geothermal power station typically range between $ 2 to $ 7 million (v) Surface instability: The plant's construction may have an impact on the land's stability (vi) Distribution costs : If energy is carried across great distances, the cost can become prohibitively expensive (vii) Operation without a requirement of steam: If temperature is not properly managed, it can result in melting or other problems where energy is not dispersed or utilized effectively (Anyogu *et al.*, 2021). It has been expected that the global consumption of geothermal energy to grow up to 200 TWh in the last two years (i.e. 2020) (Anderson and Rezaie, 2019). The annual growth rate of the consumed energy was estimated to be equivalent to 7%. The United States, Italy, Indonesia, Philippines, and New Zealand lead the world in geothermal power generation (Bishoge *et al,*. 2019).Tanzania has significant geothermal energy resources, but they have yet to be completely measured (Bishoge *et al.*, 2019). The assessment of geothermal energy resources began in 1976 and Tanzania now has a potential of around 5000 MW capacity that can be generated by geothermal power resources, with the majority of prospects situated in the East Rift Valley system in Africa (Bishoge *et al.*, 2019). Tanzania's geothermal blessings and prospects are divided into three major zones: the north-eastern zone, which includes the some areas of Kilimanjaro, Arusha and Mara; the south-western zone, which particularly includes the regions of Mbeya and Rukwa; and in the eastern parts of coastal beltzone, which includes the Rufiji basin and is associated with magmatic and rifting encroachments (Bishoge *et al.*, 2019). The force of the geothermal power source can go from 60 °C to 350 °C. Power stations are not practical for temperatures under 80 °C attributable to the decreased by and large framework proficiency (Qaisar *et al.*, 2021). Temperature is utilized to sort geothermal assets for various applications like traditional power age, double cycle power age and warming (heat siphon). The conceivable utilization of geothermal energy can change contingent upon the degree of temperature of the geothermal liquid, geographical example, and hydrogeological highlights (Carotenuto *et al.*, 2016; Aslam *et al.*, 2021). Different Geothermal innovations are utilized either straightforwardly or by implication for various applications, for example, electric frameworks, locale warming frameworks in chilly zones, cooling frameworks in hot zones (Carotenuto et al., 2016, Iorio et al., 2020, Yu et al., 2022) Melkior *et al.*, 2018 ; Brown *et al.*, 2022) . Direct utilizations of hotness got from geothermal energy asset are advantageous to climate and are currently supplanting conventional wellsprings of energy (petroleum derivatives) (Carotenuto et al., 2016; Iorio *et al.*, 2020; Yu *et al.*, 2022). Power energy creation at temperatures above 90°C; direct uses of nuclear power for modern interaction, farming creation and space warming at temperatures underneath 90°C; extraordinary tasks at liquid temperatures lying somewhere in the range of 30 and

50°C especially in unique volcanic regions in addition to carbonates springs *(*Carotenuto *et al*., 2016; Carotenuto *et al*.; Iorio *et al*., 2020) .Geothermal fields having low temperatures have been outfit for modern applications in China, Hungary, Iceland, Hungary, Germany, Russia, Turkey, France, and different countries for various many years, and many creators have as of late proposed the utilization of geothermal energy alone or related (incorporated) with a few other non-ordinary energy sources (Carotenuto *et al.* , 2016; Iorio et al., 2020). For instance, in Kamchatka, Russia, geothermal field with low temperature field of fleeting beginning has gathered warm water starting around 1966, generally in the way of artesian stream, to supply the different pools, the area warming with two settlements, nursery planting, and fish rearing (Carotenuto *et al*., 2016; Iorio *et al*. 2020). EGS (Enhanced Geothermal Systems) are man-made geothermal tanks shaped by pressure driven deep oil drilling and other feeling methods in ultralow porousness rocks. The chief object is to cultivate great conditions for course of water and hotness mining to help surface energy uses, for example, region warming, power creation, and direct modern hotness use *(*Carotenuto *et al*. 2016; Melkior *et al*., 2018).Technological headways in pressure driven cracking and multistage pressure driven breaking have changed stream porousness shale as of late. Despite the fact that the exorbitant cost stays a huge hindrance, it is trusted that this innovation will be utilized to configuration crack designs with a tremendous surface area of EGS (Brown *et al*., 2022). Since the 1970s, numerous endeavours have been made to develop savvy EGSs. For instance, the EGS at Fenton Hill in New Mexico was the main work to gather heat from permeable stone. Numerous upward pressure driven crevices were worked to associate and permit course of water between two wells (openings) separated, extricating heat from 190 degrees Celsius at 3500 meters profundity. Ventures of a comparative sort have been done in Korea, Australia, and Europe. With obstacles from seismicity, association, and monetary achievability, these have met with lopsided achievement. One more late undertaking is the warm field known as Qiabuqia in China, which has been dug to a profundity of 3.7 km (Brown *et al*., 2022).

There are numerous classifications for geothermal energy resources, based upon enthalpy or temperature (basic types are dry steam energy plants, flash steam energy plants and binary ORC (organic rankine cycle) or the concept of exergy (Qaisar *et al*., 2021; Anderson and Rezaie, 2019). It is primarily classified into three types based on the temperature or enthalpy, namely low, medium, and large enthalpy resources. The major vocabulary used for classification based on exergy is SER (specific exergy rate) or SEI (specified exergy index).

Geothermal resources are divided into three categories based on SER or SEI: low, high, and intermediate exergy resources. Because it is not possible to determine the type of fluids based solely on temperature or enthalpy, SEI-based categorization of geothermal energy is also necessary (Anderson and Rezaie, 2019). For saturated steam and water, the SEI value ranges from 0 to 1 (Qaisar *et al*.,2021).Geothermal resources can directly be utilized for heating purposes. Geothermal power can be used to generate power, desalinated water, and space cooling (Carotenuto *et al*., 2016; Ahmadi *et al*., 2020). Also, apart from the basic kinds of power generation via geothermal energy resource (i.e. dry steam energy plants, flash steam energy plants and binary ORC) (Qaisar et al., 2021; Anderson and Rezaie, 2019; Ahmadi, *et al.*, 2020), it can also be integrated by other energy resources: Incorporation of geothermal power system in conjunction with other energy sources: Cascading refers to the pairing of various power producing systems. Geothermal power nowadays is currently combined with solar, biomass, TEG (thermoelectric generators), tri-generation, hydrogen production, and other kinds of direct use Ahmadi, Assad et al. 2020). When geothermal resources are extracted, there is frequently residual enthalpy in the geo-fluid that might be utilized in a new application. A moderate temperature from geothermal deposit can produce power in an ORC power plant, where the heating rate of the geothermal saline is sufficiently high to be utilized in heating (heat pump) process (Anderson and Rezaie, 2019):

(D) **Geothermal and solar photovoltaic (PV) hybrid systems**: Hybrid solar geothermal energy systems are characterized by their simplicity to set up in a variety of operating circumstances. They have been demonstrated to be reliable by employing low-cost collectors to set prices comparable with other kinds of electricity. There is also the possibility of multi-generation (heating/cooling) applications, as well as significant capital cost reductions through shared equipment within systems. The drawbacks of hybrid geothermal power systems include reduced efficiency cycles, rusting and scaling difficulties, and multi-generation facilities that necessitate numerous heat sinks (Carotenuto *et al*., 2016; Iorio *et al*., 2020; Ahmadi *et al*., 2020).

(E) **Other geothermal energy based hybrid systems**: While the majority of research for geothermal-hybrid systems has focused on pairing geothermal and solar technologies, there has been significant research into systems that use geothermal technology in conjunction with organic material (biomass), hydrogen production, TEG, and cogeneration with additional fresh-water production (Anderson and Rezaie, 2019; Iorio *et al*., 2020).

(F) Improved geothermal systems: Drilling to a depth where the mantle's temperatures are adequately hot to transfer heat from the permeable rocks into a working fluid is required for enhanced Geothermal Systems (EGS) (Anderson and Rezaie, 2019; Melkior *et al.* 2018). The fluid is then directly discharged, and energy is generated by any of the existing power plant types. Hot dry rock is relatively prevalent in the planet with average thermal gradients ranging from 25 to 30 °C/km deep. Some preliminary thinking suggests employing thick fluids to boost circulation pathways and lower rock permeability, allowing for smoother circulation starting from the injection well into the extraction well (Anderson and Rezaie, 2019; Melkior *et al*. 2018).

Before drilling and designing geothermal plant, knowing scientific-technical data connected to the possibility of geothermal resources and the sustainability of utilization is a critical task for assessing the economic feasibility of geothermal exploitation and the creation of future project plants. More information such as the applicability of system periphery conditions during long-term utilization, the interference of fluid extraction and reinjection during production, and the efficacy of geothermal production systems, can be gathered in this manner. Numerical simulation is recognised as a critical instrument for the development and evaluation of geothermal energy, which is otherwise regarded as highly dangerous (Carotenuto *et al*., 2016; Iorio *et al*. 2020).

As it has made sense of over, the improvement of sustainable power innovation in Tanzania is at primer stage respectively (Bishoge *et al*. 2019). Be that as it may, miniature hydro power and sunlight based PV systems have been executed in off-network areas of the nation [respectively (Bishoge *et al*., 2019). Hydro power age innovation is experienced and because of its high capability of hydro source a few undertakings of different scales are being carried out off-network areas (Melkior *et al*., 2018; Ngowi *et al*., 2019; Kichonge, 2018). Topographically, Tanzania is found near the equator and in this manner it gets enormous measure of sun powered radiation in practically all pieces of the country. The focal area has most elevated capability of sunlight based energy (Mas'ud *et al*., 2016; Aly et al., 2017). The main reason for this work is to execute achievability study and make approval by planning cross breed framework utilizing miniature hydro power and sunlight based PV advances. In this manner, accessibility and high capability of hydro and sun based energy sources in Tanzania can be utilized to configuration decentralized power creating frameworks including ideal half breed power plants for rustic regions. Comparable investigations have been performed locally and universally concerning streamlining of hydro-sun based PV half breed electric creating frameworks for off-lattice areas. A portion of these examinations have principally utilized hydro energy source from enduring waterways, water streams and horticultural water system channels to lead practicality studies to survey the plausibility of producing power for off-grid areas (Poudel, 2018; Chisale, 2019; Syahputra and Soesanti , 2020).

According to the case studies, there are many research methodologies using simulation and approaches have been applied (Al-Falahi *et al.*, 2017, Khan et al., 2018; Zahraee *et al*., 2016). Presently, many researches in engineering field are carried out using AI optimization techniques (Zahraee *et al*., 2016).

The peculiarity of this exploration is that as per the creators' perception and experience power age by utilizing capability of non-enduring feeder (Installation of ROR little power station hybridized with sunlight based energy in addition to batteries) which isn't completely taken advantage of and the use of customary methodology of estimations . The goal of this study is to upgrade the sustainable power based crossover framework to create power for the chose site. This study investigates the dismissed hydro energy capability of a non-perpetual feeder consolidated with the accessibility of plentiful sun oriented energy source. The feeder is considered to have significant undiscovered high capability of producing power for country networks of in the locales of drawn out high precipitation of Tanzania. This examination work attempts to investigate more expansion of nearby environmentally friendly power sources. In the review, the assessed water potential gets from deserted capability of existing feeders in the nation including the Ikata feeder which was assigned as a contextual analysis for this examination. The feeder is raised and having appropriate water head and adequate water stream during stormy season that might be sufficient for supporting the rustic charge in the country. Tragically, this capability of the feeder stays undiscovered. In the stormy season, this feeder has enormous measure of water low which is basically streaming down into the extremely durable waterway called the River Shongo. This waterway gives water primarily to drinking and little rural water system locally. The review is expected to make mindfulness about how the active energy of water from the neglected capability of non-perpetual feeder in zones of ample precipitation and sun based energy source through the hybridization of the two environmentally friendly power sources and battery energy can be tackled. The review has likewise considered the advantage of high sunlight based radiation accessibility. Tanzania is close to the equator and hence receives a significant amount of solar radiation. The potential of a non-perennial tributary water source and solar power source is thus merged into an off-grid HRESS. The off-grid hybrid system is optimised by minimising costs such as total NPC and COE.

These days, many explores are being completed utilizing different fake canny (AI) strategies. Among of these AI techniques incorporate the recently developed counterfeit wise (AI) improvement approaches called PSO, GWO, and GWO-PSOHD. The significant benefits of the PSO are simplicity, effortlessness of strategy; incredible combining degree, less necessity of capacity, and decreased dependence on the starter focuses (Hadidian-Moghaddam *et al*., 2016). The GWO calculation comprises of elements, for example, extraordinary combination degree, execution freedom and power. The GWO-PSOHD improvement strategy is additionally an of late settled of which GWO is joined with PSO for working on the functioning capacity of GWO (Hadidian-Moghaddam *et al.*, 2016). The GWO-PSOHD method has been checked of being basic, powerful, simple, and serious. Thusly, by utilizing above named AI moves toward additional advancement results have been found out. The AI calculations have been carried out in the MATLAB program. Through the improvement results which are gotten from the HOMER programming and AI techniques, relative review has been made for approval purposes. The AI enhancement procedures give lower upsides of complete NPC and COE of the proposed cross breed energy framework. In synopsis this paper adds to the further investigation of unexploited potential to broaden sustainable power hotspots for provincial jolt. Additionally, in the paper the assessed limit of the feeder under study has assessed through customary methodology which is seldom utilized. Likewise, the paper includes uses of AI methods PSO, GWO, and GWO-PSOHD calculations for measuring off-matrix framework which further diminish NPC and COE. Additionally, in the paper the framework is streamlined by considering the framework unwavering quality.

These days, many explores are being completed utilizing different fake keen (AI) techniques. Among of these AI techniques incorporate the recently created counterfeit smart (AI) streamlining approaches called PSO, GWO, and GWO-PSOHD. The significant benefits of the PSO are straightforwardness, effectiveness of system; extraordinary combining degree, less prerequisite of stockpiling, and decreased dependence on the starter focuses. The GWO calculation comprises of highlights, for example, extraordinary assembly degree, execution autonomy and strength (Hadidian-Moghaddam *et al.,* 2016). The GWO-PSOHD enhancement strategy is likewise an of late settled of which GWO is joined with PSO for working on the functioning capacity of GWO. The GWO-PSOHD method has been checked of being basic, successful, simple, and cutthroat. Accordingly, by utilizing above named AI moves toward additional enhancement results have been found out. The AI calculations have been carried out in the MATLAB program. Through the advancement results which are gotten from the HOMER programming and AI techniques, near concentrate on has been made for approval purposes. The AI improvement methods give lower upsides of absolute NPC and COE of the proposed cross breed energy framework. In outline this paper adds to the further investigation of unexploited potential to differentiate environmentally friendly power hotspots for provincial charge. Also, in the paper the assessed limit of the feeder under study has assessed through conventional methodology which is seldom utilized. Additionally, the paper includes uses of AI procedures PSO, GWO, and GWO-PSOHD calculations for estimating off-network framework which further lessen NPC and COE. Also, in the paper the framework is streamlined by considering the framework unwavering quality.

7.1 AN OVER-ALLDESCRIPTION OF ELECTRICITY GENERATION VIA OFF-GRID HRESS

Tanzania has a surplus of SRES's, but it has not been adequately utilised to fulfil electrical demand, particularly in rural and remote communities. Table 7.1 depicts Tanzania's renewable energy potential.

Table 7.1 Tanzania's potential of renewable energy sources

Renewable energy source	Approximated potential	Growth in percentage
Mega hydro energy	4.7 GW	12%
Small hydro energy	485 GW	2 %
Solar energy	Greater capacity than 200 W_p/m^2	Solar radiation: 215 W/m^2,
Biomass energy	Greater capacity than 500 MW	34 Million m^3/year
Geothermal energy	5000 MW	-
Biofuels	Existence of plants for ethanol and biodiesel production	-
Wind energy	Greater speed than 8 m/s	-
Tidal and wave energy	On -going assessment	-

The URT now strongly promotes renewable energy options for electricity generation. It is expected that by 2050, renewable energy sources would account for 100 percent of total electricity generated in the country. According to this forecast, overall electricity capacity will be around 60 gigatonnes (Bishoge *et al.*, 2019). Hydro and solar energy are not just technologies, but they are also preferred. The power provided by hydro energy is both dependable and economical. Solar energy systems have been installed in residences, health care facilities, clinics, and schools. The following are descriptions of hydro and solar energy sources:

1.17.1.1 Hydro Power Source

The generation of electricity via an off- grid HRESS is a mix of multiple yet complimentary energy sources. Hybrid technology is both dependable and cost-effective. There are three types of hybrid power generation configurations: series, parallel and switched hybrid configurations. The parallel hybrid arrangement is the most ideal of these three options since it is a combination of sources for reliable power and the energy sources within it function independently. Micro-hydroelectric and SPV systems are dirt-free. The kinetic power of water is turned into mechanical energy by a turbine, which is subsequently transferred to electricity by a generator.

According to the producing capacity, micro-hydro power (MHPS) refers to systems with capacities ranging from 5 kW to 100 kW. Furthermore, MHPS capacity may increase up to 200 kilowatts. The power generated by MHPS is dependent on water head and flow rate. This power can be calculated using equation 7. 1 (Syahputra and Soesanti, 2020):

$$P = Q * H * \rho_{water} * \text{ g} \tag{7. 1}$$

Where P stands for MHPS power output in watts (kW), ρ_{water} refers to the water density in kg/m3, Q stands for water flow rate in m3/s, and H defines the water head in m. MHSP can create power that can be used to improve socioeconomic activity in remote communities.

The majority of hydropower plants are categorized as ROR hydropower plants. The power generated by ROR facilities is not fixed; it varies with the flow of the river on a daily, monthly, and seasonal basis. ROR plants can generate energy only if there is sufficient amount of water in the river channel. Electricity generation stops if river discharges fall under the minimum technical inputs. It is worth mentioning that ROR hydro power installations with pondage, as opposed to those without pondage, can store water for maximum electricity consumption and uninterrupted base load, particularly during rainy seasons. The advantages of ROR energy plants without pondage/reservoir for energy production include less influence on the available ecosystem, a simpler design, lower overall capital costs, smaller water heads, a shorter construction time, the possibility of decentralized electrification, and comparatively small operational and maintenance costs. In terms of resilience, adaptability, and periodic variations, design and operation are difficult tasks.

7.1.2 Solar Energy Resource

Tanzania is a tropical nation solar energy potential of 4- 7 kWh/m2/day (Mas’ud et al., 2016). Despite the availability of significant solar energy, there is a limited total capacity of decentralized facilities in rural areas. Solar energy is an intermittent source, resulting in variable power output. The amount of solar energy, orientation, temperature, and site factors all influence power generation (Aly *et al.*, 2019; Aly *et al.*, 2019). An ESS (energy storage system) is needed to store power during periods of high solar irradiance and to deliver electrical load during periods of low solar radiation. The cost of energy storage is lowered in an off-grid HRSS's, and their performance is also reliable (Aly *et al.*, 2019; Bakhtiari and Naghizadeh, 2018).

Solar PV technology generates electricity through the use of photovoltaic panels, charge controllers, deep cycle batteries, and power converters. Equation 7. 2 (Syahputra and Soesanti , 2020) is used to calculate power output.

$$P_{Max} = \frac{E_{el} * I_{STC}}{E_{global} * PF} \tag{7.2}$$

P_{Max} , defines peak power (KW p) under standard test conditions (STC), Eel E_{el} describes actual total electricity output (kWh/year), I_{STC} describes the irradiance solar radiation (1 kWh/m2) under STC, E_{global} explains annual global solar irradiance (kWh/m2/year), and PF stands for performance factor.

7.2 ENERGY DATA COLLECTION AND ANALYSIS

Based on the innovation and concept of hybrid mhps-spv with ESS system, a case study is done at a place where there a high possibility for a non-perennial stream is in sustained rains with a high potential for solar energy. This part that follows below provides a brief explanation of the study's field of inquiry and methodology:

7.2.1 Description of Area of Study

Ikukwa village is located in the Mbeya rural district of Tanzania's Mbeya region (Latitude 8° 42.6' S, Longitude 33°27.9'E). The community is divided into 14 sub-villages, with a total of 570 households. Geographically and logistically, the community is located beyond Mount

Mbeya, where immediate grid connection from Mbeya city has proved problematic. As shown in Figure 7. 1, the research is located at latitude 8°45.4'South and longitude 33°17.4' East. This study is divided into three major phases: determining the theoretical capacity of SPV and MHPS, analyzing the energy consumption of Ikukwa village, and optimizing the suggested hybrid system. The simulation by HOMER pro software is used during the techno-economic examination of the hybrid renewable energy-based micro grid system.

Strategically, during the blustery season the way to the area of study is additionally obstructed. As of late, just 40 families out the absolute number of families of the town are associated with the public lattice circulated by Tanzania Electricity Supply Company (TANESCO). Accessibility of framework network in the entire town is comparable to 7%. One reason is that this town has scattered families and unfortunate populace thickness. Table 7.2 demonstrates the situation with matrix availability rates by sub-towns. This town comprises of feeder called Ikata. The Ikata feeder is a non-perpetual water stream having a high capability of producing electric power during a blustery season. This surge of water streams down from the slopes encompassing Mount Mbeya to the River Shongo. Figure 7.2 demonstrates the Shongo River which gets water supply from Ikata feeder at the town. Different feeders which convey water supply to River Shongo are like Ho, Ilwilo and Igodela. The lasting River Shongo upholds Ikukwa inhabitants by furnishing them with water supply for drinking and water system for agrarian exercises through little channels. As per the field work completed by creators, Ikata feeder is more ideal for dispersed electric age than the Shongo River in light of the fact that the previous has significant water head and is nearer to the proposed site of study. It is notable that disseminated age is introduced near the electrical burden for further developed unwavering quality and proficiency. Consequently Ikata feeder is considered to have high capability of producing power when hybridized with sun oriented PV creating framework. Besides, Mbeya district where Ikata feeder is found by and large has high precipitation of a delayed timeframe for adequate water stream rate during stormy season. The cross breed of MHPS of run-over-stream class and sun oriented PV creating framework is planned to increment power availability to sub towns of Ikukwa town, valuable for decreasing the test of successive and longstanding burden shedding from public matrix organization and can uphold useful exercises in the Ikukwa people group.

Figure 7.3 depicts the steps involved in this research endeavour. This research procedure includes steps such as a literature review, field evaluation, energy analysis for the proposed hybrid system, including data collection for miscellaneous weather information, source of energy and electricity requirement assessments, achievement of the optimal off-grid

HRESS based on the least total NPC and COE, and a decision on whether the analysis yields optimal results or not. If this is the case, the best results are given, and eventually, conclusions are drawn. The analysis, on the other hand, is repeated until ideal results are acquired.

7.2.2 Methodology

The collected statistics regarding MHPS's hydro potential were obtained via a field appraisal at the proposed site. The hydro energy study focuses on the Ikata tributary in Ikukwa hamlet, Mbeya rural district, Mbeya region, Tanzania. Traditional methods were used to collect direct measurements for estimating water flow rate and head metrics in this tributary. Furthermore, the potential for solar radiation and other meteorological information was obtained from the National Aeronautics and Space Administration (NASA) databank and TMA (Tanzania Meteorological Authority) through MMS (Mbeya Meteorological Station) correspondingly (NASA, 2019; TMA, 2019). Assorted meteorological data are critical for understanding how temperature fluctuations and rainfall affect the power output of MHPS and the planned hybrid energy system. Table 7. 2 indicates status of national grid connectivity (TANESCO) at Ikukwa Village [Source: Survey by authors before 31. 07.2019].

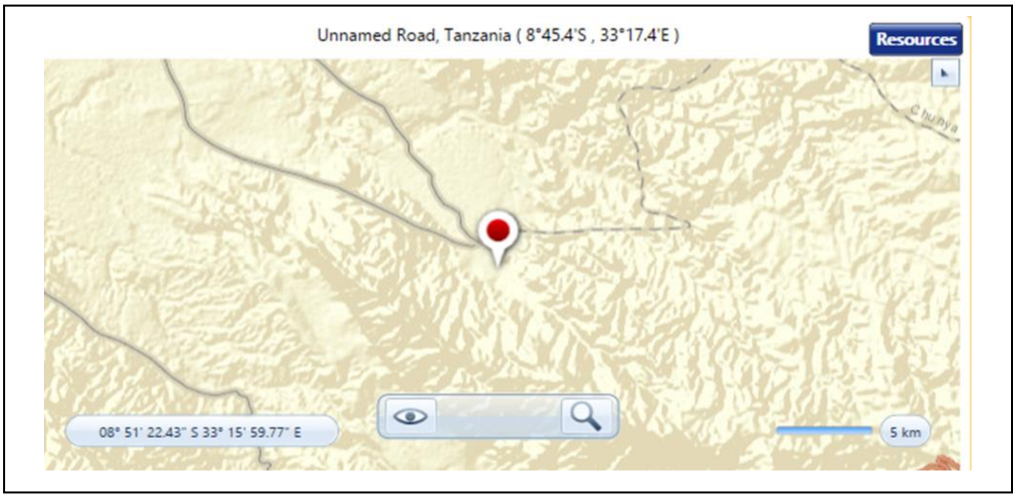


Figure 7.1. Location of Ikukwa village in rural areas Mbeya region, Tanzania

Table 7.3 indicates Total electrical load at Ikukwa village (7% access to grid from TANESCO [Source: Survey by authors before 31.07.2019]. Table 7.4 presents total electrical load for small communities at Ikukwa village without access to electricity [Source: Survey by authors before 31.07.2019].

Figure 7.2. Shongo River receives water supply from Ikata tributary at Ikukwa village from the hills of Mt. Mbeya, Mbeya region, Tanzania (Photo during dry season)

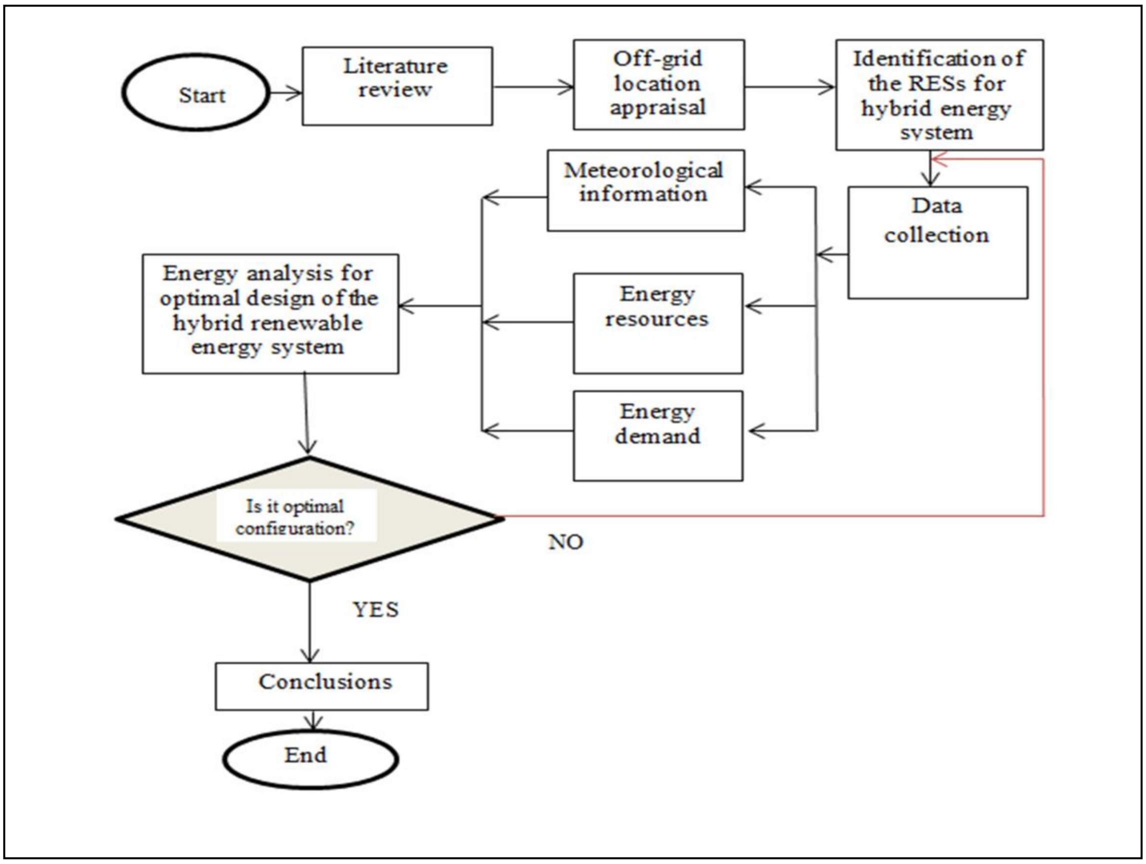


Figure 7.3. Steps for implementing the research

Table 7. 2: Status of national grid connectivity (TANESCO) at Ikukwa Village [Source: Survey by authors before 31. 07.2019]

Sub- village	NH	Grid connected customers	% of grid connected NH
Mdonya	26	0	0
Kiwanja	38	0	0
Unguja	28	0	0
Shongo	33	01	0.2

Juakali	42	0	0
Ujamaa	34	01	0.2
Kariakoo	41	0	0
Ukwaheri	29	0	0
Ikukwa	52	14	2.5
Mbuwi	42	0	0
Zongo	59	08	1.4
Itende kati	90	10	1.8
Mahonza	28	05	0.9
Itende juu	28	01	0.2
Total	570	40	Approx.7. %

NH = Number of households

Table 7.3.Total electrical load at Ikukwa village (7% access to grid from TANESCO [Source: Survey by authors before 31.07.2019]

Name of small communities of Ikukwa village	Estimated load in watts (W)
Ujamaa	115 803
Ikukwa	149 531
Jua kali	141 482
Kiwanja	52 306
Ukwaheri	46 079
Itende juu	33 063
Mbuwi	80 626
Mahonza	49 799
Kariakoo	79 475
Unguja	33 404
Mdonya	61 372
Zongo	100 825
Shongo	42 448
Itende kati	129 953
Total	1116166

Table 7.4: Total electrical load for small communities at Ikukwa village without access to electricity [Source: Survey by authors before 31.07.2019]

Name of the community without electricity	Estimated load in watts (W)
Juakali	98072
Kiwanja	52306
Kariakoo	79475
Mbuwi	80626
Mdonya	70790
Ukwaheri	46420
Unguja	33 404
Total	461093

7.2.3 Application of HOMER Platform and AI Optimization Techniques

HOMER programming is a miniature matrix demonstrating programming. It was laid out by public sustainable power lab (NREL) under the division of energy in United States of America (USA). HOMER is well known driving programming utilized for the improvement of miniature matrix framework. It is normally utilized for practicality studies to decide ideal setup of the planned framework. The variable which is utilized for choice of the ideal setup in the reproduction is the absolute least net present expense (NPC) and cost of energy (COE) (Yusuf and Mustafi, 2018).

Notwithstanding HOMER programming, GWO calculation is utilized for the specialized and financial examination of the framework by integrating the framework unwavering quality requirement. In this particular review, loss of electrical power likelihood (LEPP) has been considered as unwavering quality limitation. The ideal framework is acquired at the most minimal absolute NPC (additionally the least COE) under dependability limits. Itemized depiction of the specialized and monetary boundaries utilized in the investigation is as per the following (Yimen *et al.*, 2020):

$$LEPP = \frac{\sum_{t=1}^{T} SPS\,(t)}{\sum_{t=1}^{T}\; P_L(t)}, \tag{7.3}$$

Where SPS is the power supply deficiency, PL is the total electrical load, and T is a year-long period of time equal to 8760 hours. If LEPP equals zero, the hybrid micro-grid system produces enough electricity to meet the load; if LEPP equals one, the system is unlikely to meet the load (Patel and Singal, 2018; Das *et al.*, 2019).

$$SPS = P_L - (P_{ghybrid} + SOC_t - SOC_{mini}), \tag{7.4}$$

where P ghybrid is the total power generated by the hybrid micro grid system, SOC (t) is the battery's state of charge at time t, and SOC mini is the battery's minimum state of charge.

TANC is the total annualised cost of the system in dollars per year. It consists of an annualised investment charge (AIC), an annualized spare charge (ASC), and an annualised fuel charge (AFC) for the energy source, as well as an annualized operation and maintenance charge (AOMC) for the hybrid system. TANC is calculated as follows in equation (7.5) (Patel and Singal, 2018; Das *et al.*, 2019):

$$TANC = ACC\,(MHPS + Solar\ PV + Baterries + Converter) + ASC\,(MHPS + Solar\ PV + Baterries + Converter) + \text{AFC}\,(MHPS + Solar\ PV) + AOMC\,(MHPS + Solar\ PV + Baterries + Converter) \tag{7.5}$$

However, because hydroelectric and solar sources of energy are free, AFC is ignored in this analysis, and salvage value is not included for simplicity purpose. The NPC can be simply stated as the sum of all expenses incurred during the project's lifespan in equation (7.6): (Patel and Singal, 2018 ; Das *et al.*, 2019).

$$Total\ NPC = TANC/CRF\ (i, Pproj), \tag{7.6}$$

Where I denotes the rate of return in percent, Pproj denotes the project's life-span in years, and CRF denotes the capital recovery factor.

COE ($/ kWh) refers to the average charge per unit of useful generated electricity. COE can be computed as in the equation (7.7): (Patel and Singal, 2018; Das *et al*., 2019).

$$COE = \ (NPC \times CRF)/EL\ , \qquad (7.7)$$

EL denotes the total yearly energy usage (kWh/year). COE can also be calculated in terms of TANC using the equation: (Patel and Singal, 2018; Das, Singh *et al*., 2019).

$$COE = \ TANC/EL \qquad (7.\ 8)$$

CRF is defined as follows in equation (7.9): (Patel and Singal, 2018; Das *et al*., 2019)

$$CRF = \ i_{r*}(1+i)^{N}/(1+\mathrm{i})^{\mathrm{N}} - 1 \qquad (7.9)$$

Where, CRF is defined as capital recovery factor, Ir equals to the interest rate and N is the life span of hybrid micro-hydro/SPV system with battery energy storage. 〖 ir is defined in the Equation 10 as follows: (Patel and Singal, 2018; Das *et al*., 2019).

$$i_r = (i - inflation\ rate)/(1\ + inflation\ rate) \qquad (7.10)$$

7.2.4 Energy Resource Assessment, Weather Data, and Load Profile

The primary objective of this examination is to advance the half and half for similar referenced innovations. A hydro energy source starts from a non-perpetual Ikata feeder. Hydro power innovation requires two significant boundaries for power age to fulfill determined need. These necessary boundaries are appropriate head and water stream rate. Evaluation of the boundaries needs profound examination of various realities viewing water stream, for example, precipitation, nature of ground, vegetation and so forth at specific timeframe. There are number of strategies both customary and current techniques are utilized for deciding previously mentioned boundaries. Nonetheless, conventional strategies are helpful for introductory assessment of energy expected particularly in a restricted time and are generally relevant in emerging nations. Along these lines, information for water head and water stream rate were gathered by conventional strategies. Information for sun oriented radiation was acquired from the NASA-SSE (NASA, 2019) and energy request was gathered from the stock of apparatuses.

7.2.4.1 Evaluation of the hydropower potential of the Ikata tributary

Section (a): Assessment of hydro energy asset for MHPS Using traditional approach

Water stream rate and head are expected data sources boundaries to HOMER professional programming and are resolved involving conventional techniques as follows (Mdee *et al.,* 2018):

(a) **Materials and techniques for assurance of water stream rate**

Assessment of water stream rate float technique is utilized. This strategy requires assurance of surface water speed, width, profundity of water stream. At last, these aspects empower computation for water stream rate.

(i) **Estimation of normal speed of water stream**

Round and hollow wooden hued floats of individual measurement and length 5 cm and 30 cm separately are utilized to evaluate water surface speed of River Ikata. Distance of 10 cm between two imprints through two bits of bamboo tree was estimated utilizing estimating tape. Stop watch was utilized to screen time in seconds for float development over checked distance. Ten-time estimations were recorded and ultimately arrived at the midpoint of. Table 7. 5 shows time measurements.

Table 7. 5**:** Time measurements

Measurement	Time (s)
1	16
2	16
3	16
4	15
5	16
6	15
7	16
8	17
9	16
10	16

Total = 16+ 16+16+15+16+15 +16 +17 +16 +16= 159.

In this manner, normal time for the development of float at estimated distance is 15 .9 s. Surface water speed equivalents to separate along the water stream per normal time which is 10m/15.9 = 0. 63 m/s

Normal water speed, V = Surface water speed × amendment factor = 0.63 × 0.85= 0. 536 m/s

(i) **Estimation of normal width of water stream**

Normal profundity of water stream was estimated utilizing conventional strategy through bits of bamboo tree and estimating tape. Bits of bamboo tree were laid at equivalent spaces across water stream and distance between two finishes was checked. Toward the finish of this interaction bits of bamboo trees were approached and from two checked closures of individual piece of bamboo tree distance which is comparable to water stream was estimated by estimating tape. Table 7.6 width measurements

Table 7. 6: Width measurements

Measurement	Width (m)
1	6.7
2	6.1
3	6.1
4	6.1
5	7.0
6	6.8
7	6.9
8	6.6
9	6.0
10	5.6

Because 6.1 m has the greatest frequency of occurrence among other width measurements, it is considered as the average width of the Ikata River's water Stream. As a result, W = 6.1 m.

(ii) **Calculation of the Average depth of the stream of water**

The depth of the stream of water was measured using bamboo tree pieces and a measuring tape. Several bamboo tree pieces were sunk vertically to the bottom of the water stream along its breadth, and the water level of each bamboo stick was noted using marker pens. These sticks/rods were pulled out to measure the distance from the indicated point of each individual component to the bottom. Depth measurements are shown in Table 7. 7.

Table 7. 7: Depth Measurements

Measurement	Depth (m)
1	1.6
2	1.6
3	1.5
4	1.3
5	1.7
6	1.8
7	1.4
8	1.2
9	1.4
10	1.3

The most profound estimation from the table above is 1. 8 m. Assessment for normal profundity of water stream is half of the most profound estimation, that is to say, d =1. 8/2 = 0.9

(i) Determination of water stream rate

Having assessed normal water speed, normal width and normal width water stream rate can be found. Water stream pace of the waterway is the result of three above named boundary. Along these lines, Water stream rate = V × w × d = 0. 536 m/s × 6.1 m × 1.3 m = 2.943 m3/s

(a) Materials and Methods for Determination of Water Head

Water not set in stone through customary or neighbourhood strategies known as carpentry technique. Materials and hardware required are estimating tape, in an upward direction raised wooden piece, that is to say, bits of bamboo tree (normally checked), and even rectangular board and bricklayer's level. A piece of chalk or marker pen is used for marking when taking measurements. Estimating estimations is utilized to take estimations for distance; bits of bamboo are upward raised to quantify level; flat board and bricklayer's level are utilized for even evening out from reference on the ground to required level on vertical piece of bamboo (set apart by chalk or marker pen). Prior to assessing water head, consumption position and area for turbine are distinguished. Table 7. 8 indicate water head measurements.

Table 7. 8: Water head measurements

Measurement	1	2	3	4	Gross head in hills
Height (m)	3.4	3.4	4.00	2.6	13 m

(c) Computation of hydropower capacity

Theoretical power potential depends on two major factors namely flow rate and head of the falling water. The potential of micro energy resource is evaluated using equation (7.1) as follows:

ρ = 1000 Kg/ m3; g = 9.8 m/ s2; Q = 2. 943 m3/s, and H = 13 m (7. 1)

Therefore,

P= 1000 ×9.81 ×2.943 ×13= 375,320.79 P = 375 kW

This is the theoretical maximum power capacity. This capacity is expected in the month of January due the highest rainfall in the location of the site project.

Section (b): Assessment of hydro energy resource using HOMER pro software

Depending on the surveyed parameters of Ikata tributary implemented in HOMER pro software Figure 7.4 indicate the annual monthly hydro flow rate. The scaled annual average water flow rate is 899 litres per second. The comparison of the two figures, namely, Figure 7.4 and Figure 7.7 indicate the fluctuation of rainfall in a year it affects the water flow rate of the tributary under study hence the power output from MHPS within proposed hybrid technology. The drastic effect of poor rainfall on water flow in the tributary is overcome by the integration of SPV system with batteries. The focus of this research is to investigate the power generation likelihood of the tributary and general functioning of the proposed hybrid energy micro grid system.

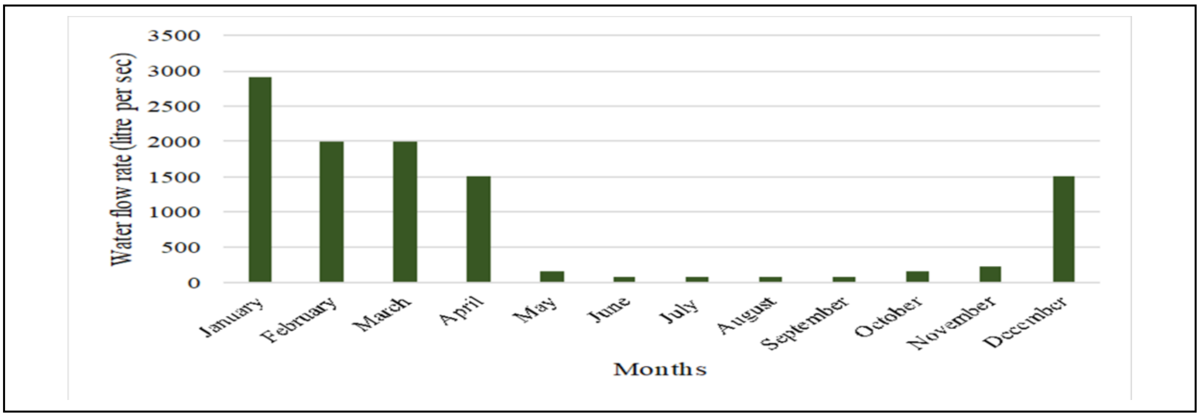


Figure 7.4. Annual monthly average water flow rate

7.2.4.2 Solar energy resource

NASA's database (NASA, 2019) is used to acquire monthly solar radiation statistics. The Mbeya region is situated at 8° 42.6' South and 33°27.9' east. Table 7.9 describes monthly irradiance and clearness index data (NASA, 2019). Solar energy data for the Mbeya region are used for a specific study area in the Mbeya rural district. For a project area, the yearly average solar radiation analysed by HOMER software is 6.11 kWh/m^2/day. Figures 7.5 and 6 show the solar energy potential for the site as well as the worldwide solar resource.

Table 7.9: Monthly sun irradiance and clearness index data [53].

Month	Clearness index	Solar energy radiation kWh/m^2/day
January	0.48	5.27
February	0.51	5.54
March	0.55	5.83
April	0.60	5.89
May	0.67	5.96
June	0.71	5.96
July	0.72	6.14
August	0.71	6.57
September	0.69	6.94
October	0.57	6.95
November	0.51	6.21
December	0.61	6.06

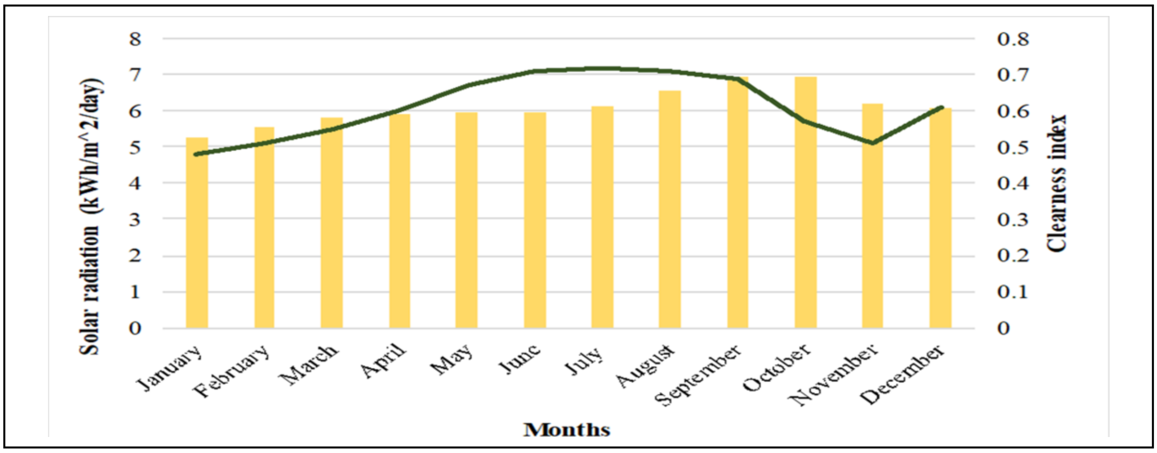


Figure 7.5. Potential of solar energy for proposed site

7.2.4.3 Miscellaneous meteorological information

Meteorological Information is gotten from Tanzania Meteorological Authority (TMA) at the part of Mbeya Meteorological Station (MMS) (TMA, 2019). The necessary meteorological information for this study is precipitation and temperature. In the period of January, the area of study has most elevated normal precipitation around 247.78 mm. Normal precipitations for May and October is 11.60 mm and 16.70 mm separately. In the period from June to September the precipitation is zero. However, precipitation in the long duration of May and October is low. In any case, water stream from the feeder under concentrate in such months however is thought to be adequate to produce power contingent upon topographical circumstances. Precipitation has enormous effect straightforwardly on measure of water stream pace of the non-lasting feeder and in a roundabout way on the activity of MHPS in the proposed cross breed energy framework. Consequently, no power will be delivered from MHPS. All things being equal, SPV system with battery energy capacity will deliver power inside the mixture energy framework from May to September. The period going from June to September is currently commonly thought to be dry season. Least temperature is knowledgeable about July around 6.10°C while most extreme temperature is in November around 26.80°C .Table 7.10 demonstrates gathered information for meteorological data (2000-2017). Table 7.8 and Figure 7.6 indicate data for rainfall and temperature for the proposed site of study.

Table 7.10 Collected data for meteorological information (2000- 2017)

Month	Avg. rainfall in (mm)	Max. temperature in °C	Min. temperature in °C
January	247.78	24.10	14.70

February	207.78	24.40	14.50
March	150.50	24.40	14.30
April	117.64	23.50	12.80
May	11.60	23.10	10.00
June	0.00	22.30	7.10
July	0.00	22.40	6.10
August	0.00	24.00	7.70
September	0.00	26.00	10.80
October	16.70	26.00	12.30
November	78.10	26.80	14.50
December	175.20	24.90	24.90

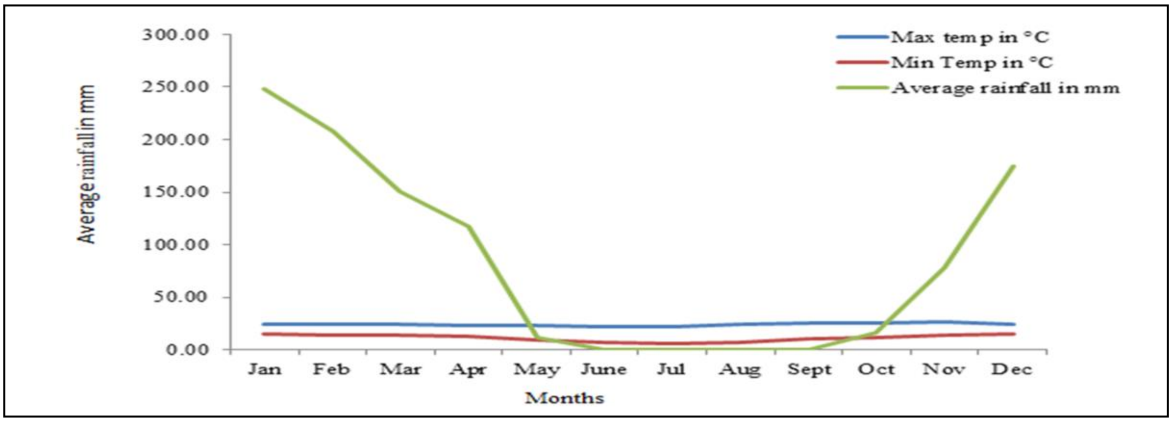


Figure 7.6. Rainfall and temperature for location of proposed project in Mbeya region, Tanzania (2000-2015)

7.2.4.4 Electrical load demand

Ikukwa village, Mbeya rustic area, Mbeya region, Tanzania comprise of 14 small societies. The heap interest around here of study is grouped into four such as small commercial, institutional, small scale businesses, and small-scale industrial loads. Normally in most of rural and remote areas electrical load demand is dominated by residential load. As it has been introduced in Table 7.2, it is just 7% of all networks approach matrix availability especially home grown houses. This restricted framework inclusion is because of dispersed populace and lack of spending plan. This study considers just 7 small societies without at all admittance to power. Other leftover sub-communities with basically access are not considered with the understanding that is for the most part stacks are associated with the appropriation arrangement of the matrix. Accordingly, information assortment for electrical energy interest of little networks without power for 100 percent is introduced in Table 4. Electrical interest for such networks has been assessed by gathering information of appraised force of expected apparatuses. In the lead position, these information have been intentionally conveyed more than 24 hour time span on the succeed sheet. Most extreme assessed day to day load profile is around 30 kW. Additionally, comparable information for the small societies with restricted admittance to power has been carried out in HOMER pro platform. Electrical burden profiles in tropical regions like Tanzania are viewed as same in all year long. The justification for why, is that, there is no super climate variety. The day to day arbitrary fluctuation has been thought to be zero. Assessed Ac load (Baseline) for the site is as per the following: Average energy is 511.1 kWh/day; normal power limit is 21.3 kW, top power is 30.31 kW and burden factor is 0.71. Figure 7.8, Figure 7. 9, and Figure 7.10 show every day electrical burden profile for the sub towns without power availability from public network acquired by succeed information sheet, day to day electrical burden profile recreated by HOMER platform and month to month normal occasional electrical load profile separately.

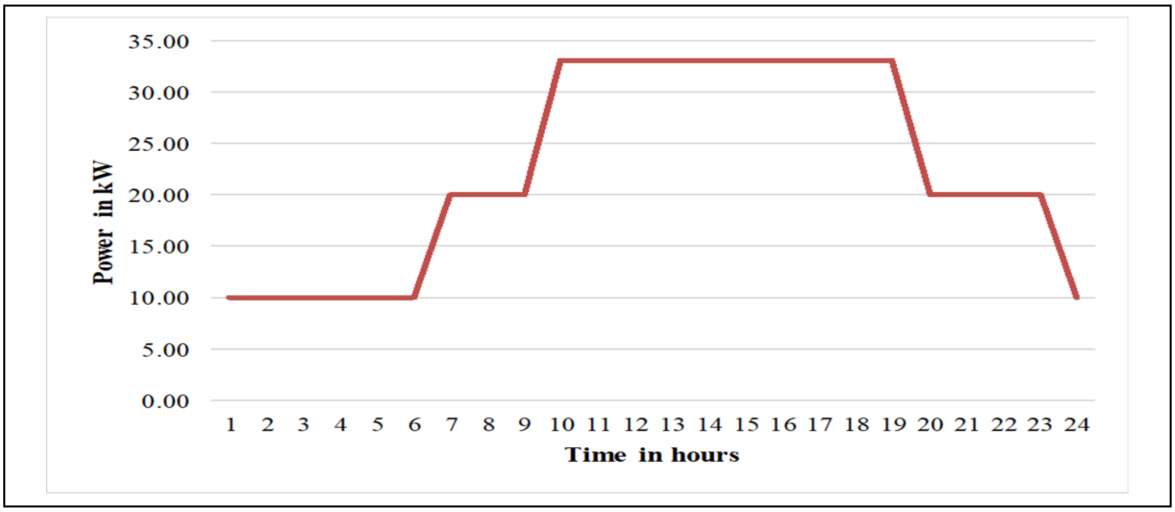


Figure 7.7. Electrical load profile for small communities without electricity connectivity from national grid at Ikukwa village, Tanzania

Figure 7.8. Electrical load over a 24-hour period simulated by HOMER pro software

In the first place, the analysis for the proposed system includes the traditional measurement approach and the soft computing tool (HOMER software). Conventional means of measurement have been employed to measure the metrics of the stream under study in the absence of measured data and financial constraints. This conventional measurement method has been utilised to assess the water flow rate and head, which are critical factors for estimating the maximum generated output from the MHPS during the rainy season.

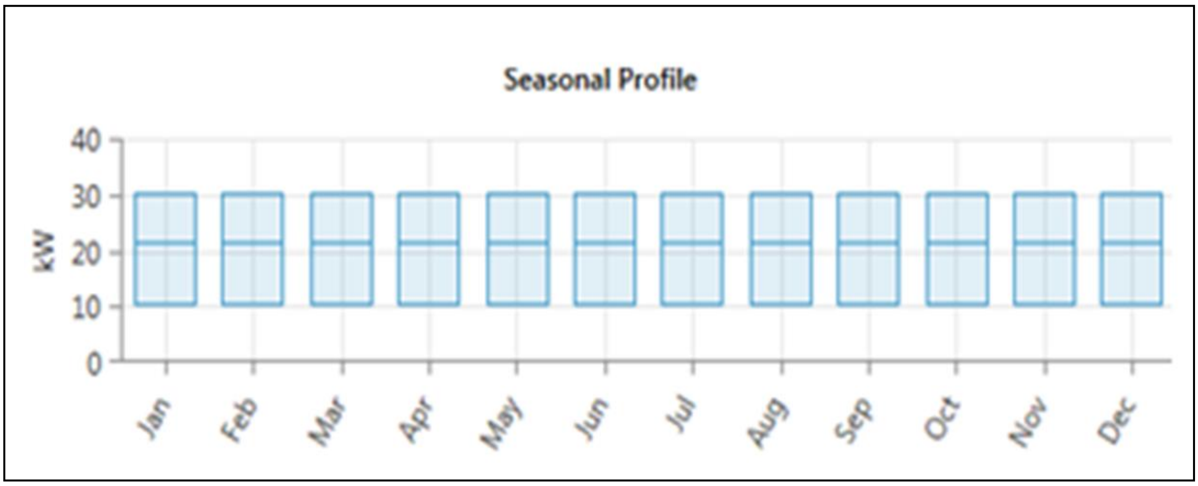


Figure 7.9. Monthly average seasonal load profile

The proposed hybridized energy system combines MHPS with SPV system integrated with batteries. The traditional approach was then evaluated in HOMER software in order to obtain the optimised arrangement of an off-grid HRESS having the lowest overall NPC. HOMER platform. This software is commonly used for hybrid energy system optimization and sizing. However, the aforementioned software has some limitations, such as constrained multiobjective functions; findings of the COE are not organised correspondingly in conformance with the findings of total NPC; no attention of DOD (Depth of discharge), hourly variability of the parameters, and fluctuations of the bus electrical energy profile.

To address the aforementioned disadvantages of employing HOMER software for optimization, experts have been constantly upgrading optimization methodologies. Meta-heuristic methods are the name given to these advanced optimization techniques. One of the nature inspired (Meta-heuristic) strategies is the GWO (Grey Wolf Optimization) strategy. The simplicity and versatility of the GWO technique are among its advantages (Syahputra and Soesanti , 2020; Hadidian-Moghaddam *et al*., 2016; Geleta *et al*., 2020).

As a result, in addition to optimization utilizing HOMER software, entire NPC optimization has been performed using AI approaches such as PSO, GWO, and GWO-PSOHD algorithms to get supplemental ideal results. According to equation 7.33, these AI approaches are also employed to minimise the overall NPC of the envisaged hybrid power technology. The optimization of the system utilizing AI techniques has been carried out in MATLAB with the parameters supplied.

7.2.5 Application of PSO Technique

The PSO algorithm is a stimulated stochastic-population-based optimization approach that has been in use since 1995. Kennedy and Eberthardt created this algorithm, and its application represents the behavioural elements of a flock of birds. Essentially, the PSO application simulates birds' social behaviour of amassing and changing themselves in their environment while hunting for appealing food stuffs, fighting against other greedy creatures using reciprocated data and shared sensitive intelligence. The advantages of the PSO approach over other exploratory optimization techniques include its simplicity, ease of use, high merging level, cheap storage requirements, and less reliance on preliminary points (Combe *et al.*, 2019).

The PSO algorithm combines individual familiarity and expertise gained from working in a group to create a simpler model that can necessary attribute complex issues. This method involves a number of agents (also known as particles) that form a group that roams around looking for the best solution. Every agent in the expanding universe changes its hovering geotargeting on its own flying knowledge as well as the flying practise of other actors in the crowd. Each agent maintains a separate position in the location of the solution. The coordinates are linked to its peak fitness rate. This rate is referred to as personal best (P best). In addition to the P best, there is also another finest fitness rate that is also considered as the best fitness level in the Particle swarm optimization (PSO) and is obtained by any agent in close proximity to that individual agent. This is referred to as the global best (G best) fitness rate (Combe *et al.*, 2019).

7.2.5.1 PSO algorithm mathematical representation

The numerical model of the PSO technique is defined in this section. The basic idea behind the PSO approach is to accelerate every item in the direction of its P best + G best positions at an arbitrarily weighted quick factor at all times. Each particle tends to change its coordinates in response to an equation and variables. The current location, current velocities, the distance between both the current position and the P best, and the length between the current location and the G best are modified. Equation (7.11) (Combe *et al.*, 2019) can be used to express the fluctuation in particle speed and location quantitatively**.**

$$\begin{pmatrix} V_{k+1}^{i} = V_{k}^{i} + C_1 r_1 \left(p_{k}^{i} - x_{k}^{i}\right) + C_2 C_2 \left(p_{k}^{i} - X_{k}^{i}\right) \\ X^{i}{}_{k+1 = X_{k}^{i} + V_{k+1}^{j}} \end{pmatrix} \tag{7.11}$$

Where, V_{k}^{i} symbolizes the position of the particle, V_{k}^{i} delineates the velocity of the particle, p_{k}^{i} stands for the finest recalled location, $C_1 C_2$ describes the reasoning and shared variables, and $r_1 r_2$ are randomized numbers ranging starting from 0 to 1.

7.2.5.2 PSO's primary algorithm

The following are the major steps in the PSO approach: (Kumar et al., 2020).

(i) Initializing the particle population size (ii) Reiterating (iii) Computing the function's fitness for personal particle (iv) Choosing the best particle from the swarm (v) Choosing the finest particle (vi) The particle's site is being modernised.

The process is reiterating until the required circumstances are met.

In addition to other AI optimization methods, the PSO application was used in this study article to examine fiscal criteria such as overall NPC and its parallel COE based on Equations (7.6) and (7.7). The PSO method was run with a constant mass of inertia, and the input parameters are listed in Table 16. The placement of a particle within the search space incorporates the energy capacities of equipment of a specific energy system structure. This PSO approach regulates the placement of the particles in the group for a single generation, tending to progress in the direction of the best solution. Every particle in the crowd is capable of comprehending its present position, velocity, that is, its own best location and the best location of the group.

For a one-year period, the implementation of the input technical requirements and power capacity comparable to the position of a particular particle is estimated. The fitness of the energy system or the overall NPC is then determined using input economic indicators if all stated restrictions are met. Any violation of any limit imposed by the energy system setup is immediately rejected. Practically, NPC is set to a large number in order to keep the squad from being drawn to this spot within the exploring region. The outputs of the previous generation are fed into the next generation. The PSO method's approach is repeated until the maximum number of generations is reached. Finally, the optimal power capacity solution for NPC is obtained (Kumar *et al*., 2020).

7.2.6 Application of GWO Technique

In the second phase of this research, the GWO technique is used to generate more optimal results for the proposed off-grid HRESS. Mirjalili and other researchers proposed the GWO technique for the first time in 2014. The primary motive for this technique is the administration and pursuit of grey wolves. The first group, known as alpha (α) wolves, has been expressed as the fitted solution in the mathematical statement. As a result, beta (β) and delta (δ)) are the second and third best solutions, respectively. The last possible solution is called mega (ω)) wolves. In the GWO optimization, the, α, β and δ and wolves lead to hunting, while the group of wolves (ω) follows the first three packs while seeking for the best global solution. Figure 7.11 depicts the societal pyramid of all wolf groups.

Furthermore, equations (7.12) and (7.13) for encircling and chasing the wolves were introduced (Hadidian-Moghaddam *et al*., 2016; Geleta, *et al*. 2020; Kumar *et al*. 2020).

$$\vec{D} = |\vec{C}.\overrightarrow{Xp}(t) - \vec{X}\,(t)|, \tag{7.12}$$

$$\overrightarrow{X(t+1)} = \overrightarrow{Xp}(t) - \vec{A}.\vec{D} \tag{7. 13}$$

In the equations, $\overrightarrow{Xp}$, $\vec{X}$ and t Specify the location vectors of the prey, grey wolf, and current iteration. Then, coefficient vectors are denoted by $\vec{A}$ and $\overrightarrow{C}$, they are computed using equations (7.14 - 7.15) as follows (Hadidian-Moghaddam *et al*., 2016; Geleta *et al*., 2020; (Kumar *et al*., 2020):

$$\vec{A} = 2\vec{a}\,\overrightarrow{R1} - \vec{a}, \tag{7.14}$$

$$\vec{D} = 2\overrightarrow{R2}, \tag{7.15}$$

Uneven vectors are represented by the symbol in the above equations $\overrightarrow{R1}$ and $\overrightarrow{R2}$. They range from 0 to 1, whereas a decreases from 2 to 0 over the course of the iteration.

The wolves may recognise the quarry's location and surround them as directed by. However, the optimal quarry position is not detected in the exploration space. Mathematically, the models for seeking wolf performance are denoted as, and. They represent the grey wolves being completely aware of the likely location of the prey. As a result, the top three best replies are saved. Then, a group of wolves must revise their locations to make them better than they are now, as specified in equations (7.16 – 7.22): (Hadidian-Moghaddam *et al.*, 2016; Geleta *et al.*, 2020; Kumar *et al.*, 2020).

$$\overrightarrow{D\alpha} = |\overrightarrow{C1}.\overrightarrow{Xa} - \vec{X}| \quad (7.16)$$

$$\overrightarrow{D\beta} = | \overrightarrow{C2}\cdot\overrightarrow{X\beta} - \vec{X}| \quad (7.17)$$

$$\overrightarrow{D\delta} = |\overrightarrow{C3}\cdot\overrightarrow{X\delta} - \vec{X}| \quad (7.18)$$

$$\overrightarrow{X1} = \overrightarrow{X\alpha} - \overrightarrow{A1}\cdot(\overrightarrow{D\alpha}) \quad (7.19)$$

$$\overrightarrow{X2} = X_{\beta} - \overrightarrow{A2}\cdot(\overrightarrow{D\beta}) \quad (7.20)$$

$$\overrightarrow{X3} = \overrightarrow{X\delta} -(\overrightarrow{A3}\cdot(\overrightarrow{D\delta}) \quad (7.21)$$

$$\vec{X}(t+1) = (\overrightarrow{X1} + \overrightarrow{X2} + \overrightarrow{X3})/3 \quad (7.22)$$

When the quarry stops moving, the wolf hunting process comes to an end. Referring to the given equations, $\vec{a}$ reduces from 2 to 0 and therefore A also decreases since $\vec{A}$ is dependent of $\overline{a}$. The quarry is attacked by grey wolves if $\vec{A}$ exists in the range starting from – 1 to 1. Furthermore, weights for the quarry's notion of distance vary by $\vec{C}$. This number is critical for storing answers from local bests, particularly in the last iterations.

The following are the general steps taken by the GWO algorithm: (Hadidian-Moghaddam, Arabi-Nowdeh et al. 2016) (Hadidian-Moghaddam *et al.*, 2016; Geleta *et al.* 2020).

(i) The establishment of a grey wolf population X_i (i = 1, 2, 3…, n)
(ii) The activation of a, A and C
(iii) The calculation of each pursuing agent's fitness, i.e. $X_{\alpha,}$ X_β and $X_{\delta.}$ $X_{\alpha,}$ X_β and X_δ stands for the finest pursuit agent, the 2nd finest pursuit agent and 3rd finest pursuit agent respectively)
(iv) While (t < The greatest number of iterations)
(v) For each agent of pursuit
(vi) The updating of the current pursuit agent's location
(vii) Termination for
(viii) The modernizing of α , A, and C
(ix) The computation of the fitness of all pursuit agents
(x) Modernization of $X_{\alpha,}$ X_β and X_δ
(xi) T = t + 1

(xii) Termination while
(xiii) Re-occurrence (Return) X_α

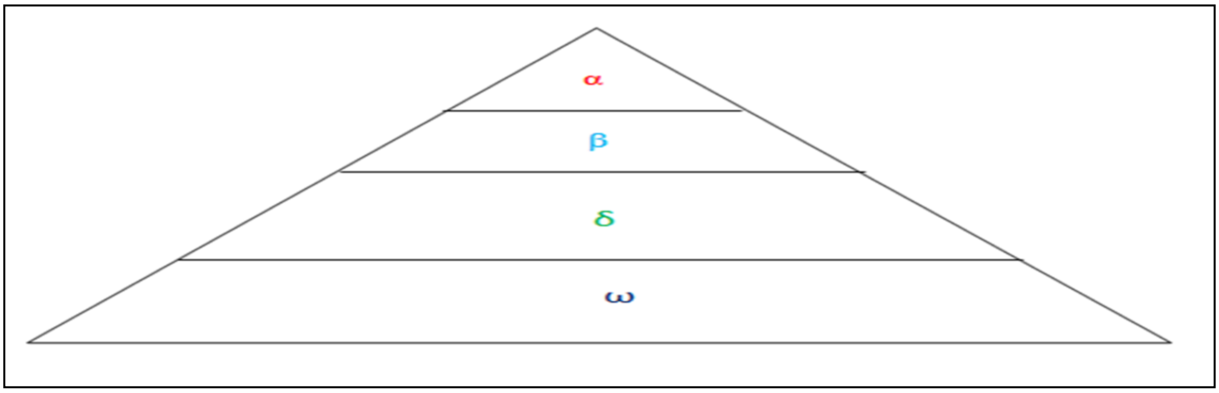


Figure 7.10. Social ladder of grey wolves

7.2.7 Application of GWO-PSOHD Technique

The GWO-PSOHD approach of improvement is an as of late advanced nature propelled procedure. It is one of the hybridized classifications of the GWO. GWO is intentionally joined with the PSO strategy for the refinement of the functioning capacity of the GWO. It's anything but an extent of this particular review to diagram, thoroughly analyze the uses of a wide range of the hybridized types of GWO. All things considered, crossover based GWO calculation has shown prevalent outcomes explicitly intermingling level, further developed results, viability, and most noteworthy unfaltering quality more discrete calculations for n. It has the capacity of dealing with both controlled and uncontrolled streamlining issues. This technique centers around the ideal arrangement by holding the better arrangements and ends the furthermost ones (Chopra *et al*., 2016; Shaheen *et al*. 2021).

In this paper, another strategy called GWO-PS0HD is researched for the streamlining of the allout NPC and comparing levelized COE. Subsequently, this study focuses on the enhancement by deciding the most un-all out NPC of inexhaustible based miniature matrix of various sources.

7.2.7.1 Fundamental practices of GWO- PSOHD approach

The stages for the GW0-PSOHD method are as follows: (Shaheen *et al*., 2021; Chopra *et al*., 2016).

(i)Initializing the search agents and describing the solution space (ii) Running the GWO method (iii) Obtaining the least magnitudes for the total number of agents (iv) Allowing the agents to use the PSO method (v) Returning the adapted location to the GWO method (vi) Repeating similar procedures until the ending conditions are obtained.

7.3 MODELLING OF INDIVIDUAL COMPONENTS INCORPORATED IN THE PROPOSED HYBRID MICRO GRID SYSTEM

In the event that absolute produced power by energy sources incorporated in the mixture miniature lattice framework approaches with energy prerequisite, this implies the complete created power meets the electrical burden. In the event that the created power is more prominent than the heap interest, surplus power is stashed in the batteries (Battery charging process). In the event that energy prerequisite is more noteworthy than the created power, the put away energy is gotten from the batteries (releasing interaction) to meet the energy necessity. In some condition energy request is more noteworthy than the amount of produced power and put away energy. Experiencing the same thing, part of the heap request need to go through shedding, in this way bringing about a deficiency of power supply. The proposed framework integrates primary parts, for example, MHT, solar modules, batteries, converter and electrical load profile. In light of these parts in addition to electric links, MHPS/Solar PV/Battery crossover miniature network framework is shaped. Accordingly, specialized and monetary examination might be completed. As indicated by the power age and electrical burden profile, unwavering quality and financial capacities can be formed. All in all, power created from the framework in the off-network mode is expected to dependably meet the expected electrical burden profile at the least expense. This power produced from sustainable sources is communicated in Equation (7.23) (Hadidian-Moghaddam *et al.*, 2016).

$$P_{ghybrid} = P_{MHPS} + P_{SolarPV} \tag{7.23}$$

Where, $P_{ghybrid}$ is the total power generated from hybrid micro grid system (W), P_{MHT} is the power generated by one turbine (W), and $P_{solar\ PV}$ is the power output form solar PV (W). The power $P_{ghybrid}$ is necessary to create enough power from renewable energy sources to meet the energy demand plus losses. To compensate for the impacts of intermittency of renewable power sources, energy storage, particularly batteries, is necessary.

The operation of the discrete components incorporated in the system determines the electricity production and performance of the full hybrid system. As a result, the modelling of the system's components is as follows (Sakulphan and Bohez, 2018):

The hydropower potential is determined by two basic input parameters: water flow rate and water head. Equation (7.24) is used to calculate the produced power output from a single water turbine, which is as follows: (Das et al., 2019; Sakulphan and Bohez, 2018).

$$P_{MTH} = \frac{\eta_{MHT} \times \rho \times g \times H \times Q_{MHT}}{1000}, \tag{7.24}$$

where, P_{MHT} is the power produced by a single turbine (kW), η_{MHT} is the water turbine efficiency (%), ρ is the density of water (kg/m^3), H is the water head (m), and Q_{MHT} is the water flow rate flowing into the water turbine (m^3/s).

In fact, hydropower turbines have practical and flow constraints. Within specified flow ranges, it can function effectively. When a single turbine is employed in a hydroelectric system, equation (7.25) distinguishes three separate operation stages as follows: (Das *et al.*, 2019 ; Sakulphan and Bohez, 2018).

$$Q(t) =\text{`}\begin{cases} 0, \; if \; Q(t) \leq Q_{Mn}, \\ Q, \; if \; Q_{Mn} \leq Q(t) \leq \; Q_{Mx}, \\ Qmx, if \; Q_{Mx} \leq Q\,(t), \end{cases} \tag{7.25}$$

Where, Q_{Mn} is the minimum flow rate, cut- off, below which electricity generation stops and Q_{Mx} is the maximum flow rate a turbine can generate electricity, and Q (t) is the existing water flow rate.

The total generated power by the MHPS is estimated as follows using equation (7.26): (Das *et al.*, 2019.

$$P_{MHPS} = N_{MHT} \times P_{MHT}, \tag{7.26}$$

Where, P_{MHPS} is the overall power created by a micro hydropower system (without pondage), NMHT is the maximum number of water turbines, and PMHT is the estimated power provided by one hydro water turbine. Table 7.11 shows the summarized technical and fiscal specifications for MHT.

7.3.1 Modelling of SPV System

A SPV system is designed by calculating the appropriate number of solar panels. These solar panels convert sunlight into direct current power. A solar panel is a collection of PV cells. The output generated per panel P SPV during a particular time in hours is specifically defined in equation (7. 27) as follows: (Yimen *et al.*, 2020).

$$P_{SPV}\,(t) = \text{SOI (t)} \times A_{SPV} \times \eta_{SPV} \tag{7.27}$$

Where, SOI denotes to the solar insolation in kW/m^2 at given time t in hours, A_{SPV} is the surface area of a single solar panel (m^2), and η_{SPV} signifies the efficiency of solar panel (%).In this study, solar panels are considered to use the maximum power point tracking system, and the impacts of air temperature are assumed to be minimal.

The total power output provided by a solar panel is stated as in equation (7.28) as follows: (Yimen *et al.*, 2020).

$$P_{solar\ PV}(t) = N_{SPV} \times P_{SPV}, \tag{7.28}$$

Where, $P_{solar\ PV}$ is the total power generated by solar panels in the proposed hybrid system. In this research work, the CSUN 410-144M In the performance assessment of the hybrid system, a model of solar panel with a maximum power capacity of 410 W was employed. Table 7.12 depicts a summary of the technical and financial standards for SPV systems that have been adopted.

7.3.2 Modelling of the Battery

Deep cycle batteries, particularly lead acid batteries, are commonly used for off-grid electricity storage (Yimen *et al.*, 2020). A thorough examination of battery charging and discharging circumstances is required to determine the best capacity. The SOC (t) of a set of batteries at a time of one hour is related to SOC (t-1), the charge's prior condition, and the power exhaustion or accumulation state from t-1 to (Yimenm *et al.*, 2020).

If $P_{ghybrid}(t) = P_{solar\ pV}(t) + P_{MHT}(t) \geq \frac{PL(t)}{\eta INV}$, the electricity generated from the supplied renewable sources is adequate to meet the load requirement PL (t) plus the surplus energy stored in the batteries. The batteries are now being charged at this time. In the following expression, the SOC (t) is defined. in equation (7.29): (Yimen *et al.*, 2020).

$$SOC(t) = SOC(t-1) \times (1-\sigma) + \frac{Pghybrid(t) - \frac{PL(t)}{\eta} INV \times \eta\ bc}{1000 \times Nb \times Cb}, \tag{7. 29}$$

Where, η INV refers to the efficiency of the inverter, η_{cb} is the battery's charging efficiency, C_b is the battery's nominal capacity in kWh, Nb is the number of batteries, and is the self-discharging rate per hour.

Likewise, in case $P_{ghybrid}$ (t) < (PL (t)) / (η_{INV}), the amount of electricity generated from renewable energy is insufficient to meet the electrical load requirement. To balance the power supply and demand, the energy stored in the batteries is discharged. SOC (t) is used to express this circumstance in equation 7.30 as follows: (Yimen *et al.*, 2020).

$$\text{SOC (t)} = \text{SOC (t-1)} \times (1\text{-}\sigma) - \frac{(PL\,(t)/\eta\,INV - Pghybrid\,(t)/\eta\,db}{1000 \times Nb \times Cb}, \tag{7.30}$$

η_{db} reflects the efficiency with which batteries discharge. Excessive charge ejection should be avoided to maintain a longer battery lifespan, and SOC (t) should be adhered to the following constraints: (Yimen *et al.*, 2020).

$$(1 - Max.DOD) \leq SOC\ (t) \leq 1 \tag{7.31}$$

Where, the greatest depth of discharge is denoted by Max. DOD.

Otherwise, (Das *et al.*, 2019).

$$S0C_{Min} \leq SOC\ (t) \leq SOC_{Max} \tag{7.32}$$

Where, SOC_{min} and SOC_{max} are the lowest and greatest values of the battery storage's level of charge.

In this study, the JUST Gel 12-100 model of the battery is selected for the hybrid system's performance study. Table 7.13 portrays technical and fiscal specifications for battery energy ESS.

7.3.3 Modelling of the Converter

A converter is an electrical component that maintains the flow of electricity in a hybrid system based on renewable energy. Inverters and rectifiers are used in converters to convert DC power to AC power and vice versa. The power from the converter's output should be greater than the maximum load. In this study, the power output of the MHPS is connected to the AC bus, whereas the power output of the SPV system and battery ESS is DC. As a result, the inverter is critical for fulfilling electrical load requirements. The device's rated power is specified in equation (7.33) as follows: (Yimen *et al.*, 2020).

$$PL = P_{inverter} = P\text{max}\,AC\ /\eta_{nverter}\ , \tag{7.33}$$

where, $P_{inverter}$ is the inverter's rated power PmaxAC is the highest AC electrical load, and inverter is the inverter's efficiency. Table 7.14 portrays the technical and economics parameters for adopted converter.

7.4 OPTIMIZATION MODELS OF THE PROPOSED SYSTEM USING GWO ALGORITHM

The MHPS/solar PV/battery bank hybrid system is optimised by considering many parameters such as the LEPP (Loss of Power Supply Probability) for system dependability, total NPC, and COE. The system's sizing is optimized by minimising the NPC and also the COE utilizing the GWO method. The specification of the objective function and constraints is required for the optimization issue. In this study, the objective function is optimized under constraints such as higher and lower boundaries based on the number of specified components and their power capacities, battery storage restrictions, and SPS for the system's technical and economic analyses. The objective function is defined within the constraints in the analysis of the system. The objective function under subjected limitations is formulated as follows: (Yimen et al., 2020; Hadidian-Moghaddam, *et al*. 2016; Geleta *et al*., 2020).

7.4.1 Objective Function with Defined Constraints

The main purpose of the optimization is to attain the bottommost cost of hybrid power generating system using GWO method. Objective function is formulated to minimize the total NPC in equation (7.34) as follows: (Yimen *et al.*, 2020; Hadidian-Moghaddam *et al*., 2016; Rizwan *et al.* 2019).

$$\text{Total } NPC = \sum_{i=(N_{SoPV}+P_{MHPS+N_{BTR}}+N_{CONV})} \frac{TANC_i}{CRP} \qquad (7.34)$$

The minimization of the total NPC according to the objective function is executed under the following constrictions in the Equations (7.35- 7.39):

$$N_{SOPV}^{mini} \le N_{SOPV} \le N_{SoPV}^{maxi}, \qquad (7.35)$$

$$P_{MHT}^{mini} \le P_{MHT} \le P_{MHT}^{maxi}, \qquad (7.36)$$

$$N_{BTR}^{mini} \le N_{BTR} \le N_{BTR}^{maxi}, \qquad (7.37)$$

$$N_{CONV}^{mini} \le N_{CONV} \le N_{CONV}^{maxi}, \qquad (7.38)$$

$$LEPP^{mini} \le \text{LEPP} \le LEPP^{maxi}, \qquad (7.\ 39)$$

Where, N_{SOPV}, N_{BTR}, N_{CONV} are quantities of solar panels, batteries, and converters respectively P_{MHT} is the power produced by micro-hydro power units forming P_{MHPS}. P_{MHPS} is power generated by MHPS from the tributary under study. Superscript maxi and subscript mini indicate maximum and minimum values of given parameters.

7.4.2 The Highest and Lowest Power Capacities of MHT

Water resource of Ikata tributary has been comprehensively discussed in the Section 3. The model for MHPS has been executed in the HOMER pro software. It should also be remembered that the range of the overall flow rate of the Ikata tributary starts from 160 l/s to 2.943 m^3/s. The minimum flow rate results during the dry season thus no power is produced from the tributary. So long there is sufficient water flow rate during rainy season and head, the designed MHPS is capable of meeting the total actual load of 40 kW (greater than daily peak load). In this study, the turbine with an inconstant speed has been taken into consideration in order to maximize the use of the micro hydropower potential within the given entire flow rate range and water head. The power capacity of the MHT can be estimated according to the Equation 23. Input parameters for sizing the MHT are tabulated in summary the Table 7.11. In this speed adjustability of MHT, the minimum power capacity (P_{MHT}^{mini}) at time in hours is anticipated to be twenty percentage of the highest turbine generation capacity (P_{MHT}^{maxi}) which balances the estimated actual load. The range of variable power from the MHT is expressed in the equation (7.40) as follows: (Yimen *et al.*, 2020).

$$8\,kW \leq P_{MHT}\,(t) \leq 40\,kW \tag{7. 40}$$

7.4.3 The Highest and Lowest Number of Components

The number of the solar photovoltaic panels, batteries and converters may change to fulfil power supply requirement. The highest and lowest boundaries of the aforesaid components are presented in equations as follows: (Sharma *et al.*, 2020).

The maximum number of solar panels is computed as follows: In the first place, data for solar irradiance (1 kW/ m^2), area (m^2) and efficiency of the model of the solar panel (20.31 %) are tabularized in the Table 7.12 to estimate power output produced by a single panel using by equation (7.41) Therefore, (Sharma *et al.*, 2020).

$$P_{SPV} = 0.402\ \ kW \tag{7. 41}$$

The maximum number of panels for the generation power capacity balancing the expected actual load is approximated in equation (7.42) as follows: (Sharma *et al.*, 2020).

$$N_{SOPV}^{maxi} = \frac{PL}{P_{SPV}} = \frac{40\,kW}{0.402} \approx 100 \tag{7.42}$$

The maximum number of batteries can be estimated using equation (7.43). In the very beginning battery capacity, C_{BTR} is determined (Sansa *et al.*, 2015; Sharma *et al.*, 2020).

$$c_{BTR} = \frac{Daily\ load\ (Wh)\times\ D_D}{System\ voltage\ V\times \eta_{BTR}\ \times \max.DOD} = \frac{511100\ \times 7}{48\ V}\ \text{AH} \qquad (7.\ 43)$$

$$= \frac{74{,}527\ AH}{48\ V} = 10,647\ \text{AH}$$

The autonomy (D_D) of 7 days gives total battery capacity equals to 74, 529 AH. Max. DOD and overall battery efficiency are both assumed to be 100% So, the highest number of batteries can be computed using equation (7.44) as follows: (Sharma *et al.*, 2020; Sansa *et al.*, 2015)

$$N_{BTR}^{maxi} = \frac{Total\ esstimated\ capacity}{Nominal\ battery\ capacity} = \frac{74{,}529\ AH}{100\ AH} \approx 746 \qquad (7.44)$$

The protection against excessive charge and over discharge of the battery should be done for securing it from damage. The highest and lowest bounds of system storage may also be considered as boundaries. The boundaries are also direct proportional to the available number of batteries and SOC. The limits for battery bank capacities are given in equation (7.45) as follows: Anand *et al.*, 2019).

$$e_{BMI} \leq e_B \leq e_{BMA} \qquad (7.45)$$

where, e_{BMI} and e_{BMA} are the least and greatest magnitudes of capacities of battery bank. These storage capacities are direct proportional to the available number of batteries and SOC and are computed in Equations (7.46 - 7.47) as follows: Anand *et al.*, 2019).

$$e_{BMI} = \frac{N_{BTR}\times V_{N}\times c_{BTR}}{1000} \times SOC_{mini} \qquad (7.46)$$

$$e_{BMA} = \frac{N_{BTR}\times V_{N}\times c_{BTR}}{1000} \times soc_{maxi} \qquad (7.47)$$

Where, V_N is the nominal voltage of the battery (V), C_{BTR} is the battery size (AH), estimated values for soc_{mini} and SOC_{maxi} are 0.2 and 1 respectively.

The highest number of converters is calculated assumption that a single converter has rated capacity about 2000 kW.

Thus, highest number of converters is estimated using equation (7.48) as follows:

$$N_{CONV}^{maxi} = \frac{Total\ actual\ load}{Power\ capacity\ of\ one\ converter} = \frac{40\ kW}{2000} = 20 \qquad (7.48)$$

7.4.4 The Highest and Lowest of LEPP

LEPP can be computed using Equation 42 after the determination of the shortage of power supply using equation (7.43). For the straightforwardness of calculating the LEPP, in this study the equation (7.4) can be simplified into the equation (7.49) as follows: (Hadidian-Moghaddam *et al.*, 2016)

$$SPS = P_L - (P_{ghybrid} + P_{battery\ bank}), \quad (7.49)$$

If power generated from renewable energy sources plus stored power in the battery bank satisfies all energy required for 100 %, equation 4 rewritten as equation (7.50). LEPP can be estimated using equation 7. 3 as follows: (Yimen *et al.*, 2020; Hadidian-Moghaddam *et al.*, 2016; Aziz *et al.*, 2017)

$$SPS = P_L - 100\%\, P_L, \quad (7.50)$$

$$SPS = 0, \quad (7.51)$$

LEPP is determined by substituting equation 7.51 into equation 7.33 which equals to zero. It implies that the system satisfies power supply requirement when LEPP = 0.

Using the GWO method, appraisal of the objective function according to the delineated constraints is made. Sizes of components are selected within the stated limits.

Table 7.11: Summarized technical and fiscal specifications for MHT

Parameter	Specifics
Type of electric generator	Alternating current (AC)
Generated power by MHT	8- 40 kW
Efficiency of the turbine	75 %
Estimated head of turbine	13 m
Flow rate channel	160 l/s
Minimum flow rate	60 %
Maximum flow rate	115%
Life span of the project	75 years
Charge for capital/unit	50, 000 USD
Charge for replacement/ unit	43, 000 USD
Charge for operation and maintenance (O&M)/ unit	5, 000 USD /year

Table7. 12: Summarized technical and fiscal specifications for adopted solar PV

Parameter	Specifics
Company	CSUN
Panel model	CSUN 410-144M
Solar technology	Monocrystalline semi
Power capacity Pmax	410 W`
Temperature range	-40 °C – 80 ° C
Efficiency	20.31 %
Dimensions	1996 * 991 * 35 mm
Estimated area of the panel	1.98 m^2
Weight	22. 9 Kg
Tc of voltage	-0.30 %/ ° C
Tc of current	+ 0. 06%/° C

Tc of power	-0.39 %/° C
Life span of the project	25 years
Charge for capital/kW	2500 USD
Charge for replacement/kW	2500 USD
Charge for operation and maintenance (O&M)/ kW	10 USD/ year

Tc = Temperature coefficient

Table 7.13: Technical and fiscal specifications for battery energy storage bank

Parameter	Specifics
Company	Zhejiang JUST
Type of the Model	JUST Gel 12-100
Weight	30. 5 Kg
Operating temperature	25 ° C $\pm$ 3 ° C
Nominal voltage	12 V
Nominal capacity	100 AH
Peak capacity	100 AH
Efficiency of charging	90% (assumed)
Efficiency of discharging	95 % (assumed)
Highest charging current	20 A
Highest discharging current	800 A
Depth of discharge (DOD)	80 % (assumed)
Rate of self-discharge per hour	3 %
Charge for capital	USD 200
Charge for replacement	USD 200
Charge for operation and maintenance (O&M)	USD 10
Life span of the project	15 years

Table 7.14: Technical and fiscal specifications for converter

Parameter	Specifics
Rated capacity	40 KW
Inverter efficiency	90 %
Inverter efficiency	85%
Charge for capital/ unit	2000 USD
Charge for replacement/unit	2000 USD
Charge for operation and maintenance (O&M)/ unit	0 USD/ year
Life span of the project	25 years

Table 7.15: Miscellaneous specifications for GWO technique

Parameters	Value
Population size of grey wolves n	12
Maximum number of iterations, iter_{max}	100
Penalty factor, PP	10^{10}
Dimension, d	2
Inflation rate	5 %
Interest rate	3.04 %
Life span of the project	25 years
Highest capacity of micro hydro turbines P_{MHT}^{maxi}	40 kW
Highest quantity of solar panels N_{SoPV}^{maxi}	100
Highest quantity of batteries N_{BTR}^{maxi}	764

Highest quantity of converters N_{CONV}^{maxi}	20
Highest LEPP, $LEPP^{maxi}$	0..07

The input parameters for PSO approach are shown in the Table 16 as follows:

Table 7. 16: Input parameters of PSO approach

Input variables	Worth
Least search space	0
Greatest search space	10 000
Quantity of iterations	100
Size of population	50
Quantity of generations	200
Weightiness of inertia	0.6
Weightiness of cognition	1.6
Weightiness of community	1.6

Identification of viable patterns of the hybrid system is done in relation to the pre-set magnitudes of LEPP. The best possible solutions are repeated in the GWO method. The structure is updated to estimate the minimum total NPC.

7.4.5 Methodology for sizing the proposed hybrid micro grid system using GWO algorithm

Optimization parameters such as solar radiation, micro hydro energy source, and ambient temperature, electrical load data and assumed constants (data sheet) were used as input variables. Decision variables like A_{pv} and A_{MHT} were estimated by GWO algorithm for individual iteration. Then, the power from solar PV (P_{pv}) and micro hydro power systems (P_{MHT}) were estimated with variable inputs, assumed constant inputs and approximated decision variables. In order to meet the energy requirements, power is considered to be generated by MHT (MHPS) and solar PV. However, if generated electricity from aforesaid energy sources does not satisfy the load demand, stored energy from batteries is used to balance power supply and demand. The standards of LEPP were calculated for the total time in hours for a year equivalent to 8760 hours. In case any value of LEPP has been greater than the prescribed one, the decision values were then recalculated. If there was no any deviation from the predetermined value, optimization procedure was implemented. Then, the optimal size of the hybrid system is obtained corresponding to the lowermost total NPC (also COE) which is computed at LEPP equals to zero when no shortage of power supply. Table 15

indicates miscellaneous specifications for GWO technique.

7.5 RESULTS AND DISCUSSIONS FOR TECHNICAL AND ECONOMIC ANALYSIS OF PROPOSED HYBRID RENEWABLE ENERGY-BASED SYSTEM

The optimal hybrid configuration syndicates micro-hydro energy, solar energy, energy storage system and power conditioning devices. MHPS consists of main components such as water turbine and generator. SPVS comprises of solar panels, charge controllers, and batteries and converter. HOMER has been used to optimize the hybrid energy system. Figure 7.12 and Figure 7.13 indicate optimal configuration for proposed off-grid hybrid energy-based system and schematic depiction for off-grid hybrid micro hydro and solar system respectively.

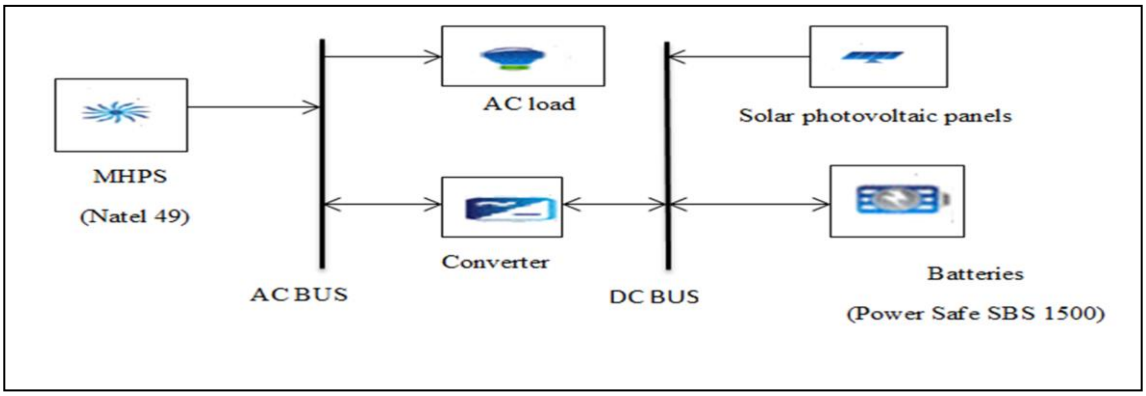


Figure 7.11. Optimal configuration for proposed off-grid hybrid energy-based system

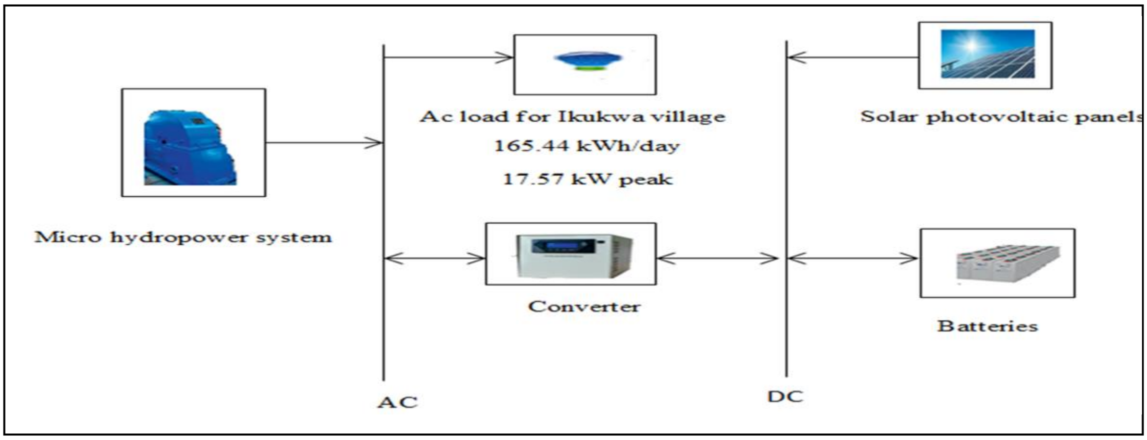


Figure 7.12. Schematic depiction for optimal configuration for proposed off-grid hybrid energy-based system

Optimal hybrid energy system has been simulated using HOMER pro software according to the technical and economic details. Simulation results are of two kinds, that is, technical and economic results. In this simulation load following has been used as dispatch strategy. Therefore, simulated results of the optimized renewable energy system are presented as follows:

7.5.1.1 Simulation results for technical analysis by HOMER software

In this section, the results of electrical power analysis that include solar and micro-hydro resource outputs, electrical power output, electricity generation and performance of individual systems/components within the proposed hybrid energy system have been presented. The system comprises of MHPS, solar photovoltaic panels, batteries and converter. The proposed hybrid system will specifically use Natel Free Jet (MHT), generic solar photovoltaic and power safe SBS 1500 (batteries). The designed system has capacity of supplying electricity to the proposed site of peak load of 30.3 kW for a period of 25 years and interest rate of 3.04%. The installed generation capacity of the designed system should be equal to or greater than the daily peak power in order to meet the load demand. In order to account for losses by ensuring reliability and availability of power, the designed system should have greater capacity than the daily peak power. Therefore, installed generation capacity is approximated to be 48 kW. Technical specifications of the system architecture are given in Table 17. The proposed hybrid energy system generates excess electricity, unmet electrical and capacity shortage are 128 483 kWh/year, 0 and 0 respectively. Table 18 indicates the generation, consumption and renewable energy utilization. Miscellaneous technical and economic details for all components in the hybrid energy system are presented in Table 19 and Table 20 respectively.

Additional related information or parameters for MHPS are that the lifespan for MHPS is assumed to be 75 years. The estimated theoretical generation power capacity of the MHPS is 375 kW considering the water head of 13 metres, flow rate of 2943 litres per second. Minimum flow rate is 160 litres per second. The maximum and minimum values of water flow of the tributary are depicted in Figure 7.4. Generally, the maximum power generated output of MHPS occurs during rainy season particularly in January. However, practically, the power output drops down depending on the rainfall dependent water flow profile of the tributary under study and other technological aspects. Technological factors are such as water discharge rates and the efficiency of the turbine. The maximum and minimum discharge rates are 115 and 60 percentages respectively. The efficiency of MHT in this study is considered to be 75 %. During dry season, that is, in the absence or shortage of water flow in the tributary, MHPS does not produce any power output. In the period starting from June to September no power is generated from the MHPS.

Specific technical and economic details are also presented in Tables 19 and 20. As it has been indicated in the Figure 7.5, the area of proposed site has sufficient solar energy potential. This potential alongside with battery energy storage assures availability and reliability of power supply. The lifespan of SPVS is approximated to be 25 years and the system is ground mounted with derating factor of 90 %. It is capable of providing power output throughout in both rainy and dry seasons for the proposed hybrid energy systems. Similarly, additional technical and fiscal details for battery energy system are also tabulated in Tables 19 and 20. Life span of battery has been assumed to be 15 years; the battery energy system employs total 288 batteries of Power safe SBS 1500. Nominal voltage for the battery is 12 volts, bus voltage is 48 volts (There are 4 batteries in series/ per string and 24 parallel strings). The battery bank has autonomy of 163 hours. State of charge (SOC) is almost constant all the time except in the period dry season from June to September. Figure 7.14 shows the annual monthly average state of charge (SOC) of battery bank. Technical and financial details for converter are given in Tables 7.17, 7.19 and 7. 20. The maximum capacity for the converter is 40 kW. The life span for the inverter is assumed to be 25 years. The performance of inverter is assumed to be 90 %. Rectifier efficiency and inverter are 90 % and 85 % respectively.

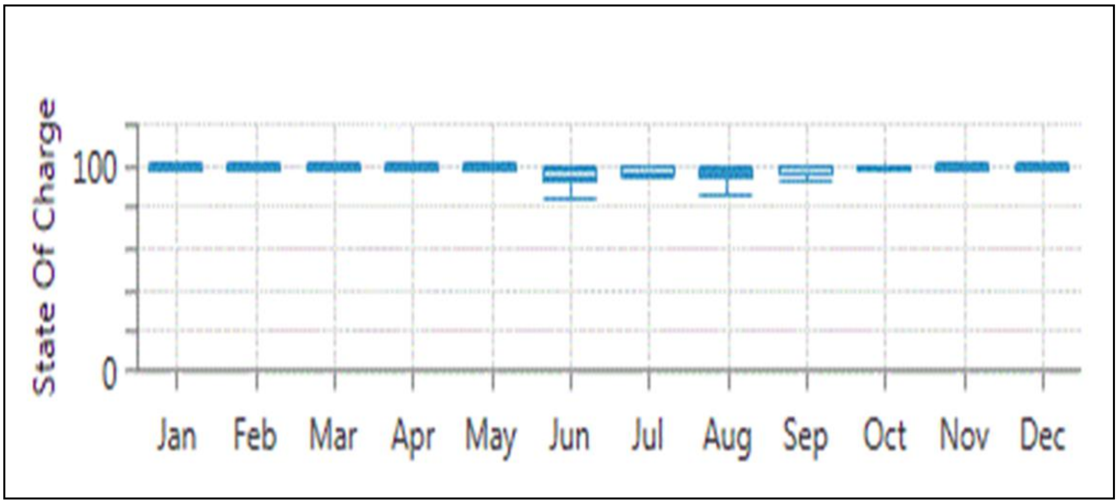
The whole hybrid energy system produces annual peak power output equivalent to 40 kW except in the period of June and September in which the major source of electricity is from solar radiation. During rainy MHPS season has higher generation capacity than SPVS. SPVS with battery energy storage gives power in all season of the year within the proposed hybrid system. In dry season, SPVS is the only alternative energy source of power. Similarly, in this period of dry season battery energy storage demonstrates highest input power to the system. Figure 7.15 illustrates the annual monthly electricity production. The annualized cost by components MHT has highest cost, followed by cost of batteries, then cost of generic flat solar and the cost of converter is the least.

Table 7.17 : System architecture

Component	Capacity in kW/ quantity in numbers
Generic flat plate photovoltaic panels	40 kW
Micro-hydro turbine/ Natel Free Jet	18.4 kW
Converter	40 kW
Batteries /Power safe SBS 1500	96 nos

7.5.1. 2 Simulation results for economic analysis by HOMER software

This section of this article presents economic analysis of a 100% renewable energy system consisting of solar photovoltaic panels, micro hydro turbine, batteries and converter. This analysis has been carried out by considering in the aforesaid period of the project. Types of annualized and net present costs by components have been analyzed. Various types of costs such as initial cost, replacement cost, operation and maintenance cost, fuel cost, salvage cost and inflation rate has been considered to be 3.04%. Table 19 shows economic input parameters for the optimized hybrid renewable energy system. Results for the total Net present cost, operating cost and cost of energy are $ 141, 397.10, $ 5293.76 and 0.1818/kWh respectively. Annualized costs by components are indicated in Table 20.



7.13. Annual monthly average SOC of battery bank

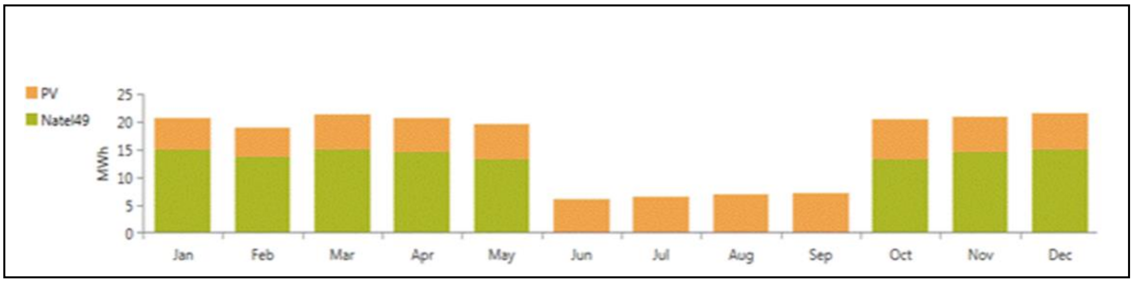


Figure 7.14. Annual Monthly Electricity production

Table 7.18: Generation, consumption and renewable energy utilization

Characteristics /Factors	Unit/Value	Percentage
Production	KWh/year	
Solar photovoltaic	75 804	39.8
Micro-hydro turbine	114 431	60.2
Total	190 235	100
Consumption	KWh/year	
AC primary load	60 386	100
DC primary load	0	0
Deferrable load	0	0
Total	60 386	100
Quantity	KWh/year	
Excess electricity	128 483	67.5
Unmet electrical load	0	0
Capacity shortage	0	0
Quantity of renewable sources	Value	Unit

Renewable fraction	100	%
Max. renewable penetration	11 347	%

Table 7.19: Economic input parameters for the optimized hybrid renewable energy system

Component	Capacity/ Quantity (kW/Nos)	Capital cost ($)	Replacement cost$	O&M cost ($/year)
MHT/Natel 49	18.4 kW	50 000	43000	110
Solar panels	40 kW	2500	2500	10
Batteries	288 Nos	2500	2500	120
Converter	40 kW	1000	1000	110

MHT=Micro hydro Turbine.

Table 7.20: Annualized costs by component

Type of cost	Components of optimized hybrid renewable energy system				
	MHT	Flat solar PV	Batteries	System converter	System
Capital ($)	3867.72	193.39	1, 547	77.35	5685.55
Replacement ($)	0	0	0	32.82	32.82
O & M ($)	5000	10	960	110	6080
Fuel ($)	0	0	0	0	0
Salvage ($)	531.22	0	281.67	6.18	819.06
Total ($)	214	203.9	225.42	214	10979.4

7.5.1.3 Limitations of the proposed hybrid energy system

Apart from the merits of including run of the river system, solar PV and batteries in the proposed hybrid system like reduced investment cost, running cost (water source and solar energy are free and renewable) , time of construction, negative impacts of environment, and power oscillations (inter- day and seasonal variability). Limitations of the hybrid system are described as follows: (Borkowski *et al.*, 2021)

(i) The operation of the hydropower system in nature is a weather dependent project. Better performance of run of the river system depends on the high precipitation in the area of study. The operation of the system may be drastically affected in the critical dry season. Suitable operation strategy is necessary in order to avoid abnormalities particularly during the dry period. The analysis of this specific system does not include control strategy to address the challenge uncertainty and unpredictability of water flow for the inter-daily, rainy, and dry periods (Borkowski *et al*., 2021).

(ii) The analysis of the system does not include the dynamics of the solar cells and hydropower excitation system (Borkowski *et al*., 2021).

(iii) The dynamic response of hydro energy system due to great inertia of water turbine owing to requirement of the battery energy storage has not been considered in the optimization Geleta *et al*., 2020).

(iv) Fixed efficiency has been used in the optimization process of the system. As water injection from the water turbine affects the efficiency of run of over the river power plant, no control has been included to balance with variable electrical load. This is not practical as far as water flow is variable due to the fluctuating hydrological situations.

(v) Limited accuracy of data collection and reliability owing to the methodological approach of using traditional methods for data measurements. In addition, data gathering does not include geological information (Borkowski *et al.*, 2021).

(vi) The analysis of the proposed hybrid system is not grid-connected. The analysis with addition of grid connection to the hybrid energy system would be helpful for the minimization of cost incurred by increasing the number of batteries in off-grid decentralized systems (Borkowski *et al*., 2021).

(vii) Complicated control and limited lifecycle of the battery is subjected to rainy and dry seasons (Borkowski *et al.* 2021).

(viii) There is no practical validation of the proposed system to gauge the performance of the system in the real environment due to the economic challenges and limited time.

(ix) The profile characteristics of the run of the river pattern may be affected by weather variations due as a result of drastic effect of global warming (Borkowski *et al.*, 2021).

(x) The analysis of proposed energy system, does not involve environmental component of sustainability. The recommendation which has been described in the conclusion is only based on authors' observation in the area of study (Mardani *et al*., 2015; Siksnelyte-Butkiene, *et al*., 2020).

For appropriate performance analysis of the hybrid system, artificial intelligent based control strategy should be implemented.

7.5.1.4 Assessment criteria of the proposed hybrid energy system

The proposed hybrid system consisting of MHT, solar PV and batteries has been optimized using monthly averages flow of water from the tributary under study and global solar radiation. The tributary is located in one of the rural areas of Mbeya region in Tanzania having prolonged high rainfall. Also, the tributary is well elevated lying in mount Mbeya having sufficient water flow particularly during wet season mainly contributed by high rainfall and few months after the rainy season. The water flow of the tributary is discharged into the River Shongo which provides water for the livestock and local irrigation schemes of agriculture at Ikukwa village. The water flow from the tributary is deemed to have a potential of contributing energy in the proposed system in the wet season. The area under study is also exposed to the sufficient coverage of sunlight during dry season. Solar energy can be harnessed to generate electricity in the hybrid system. However, sunlight is absent at night time and during rainy season and therefore battery energy storage is necessary for covering the excess or shortfall of power supply and for ensuring the fast response of off-grid hydro energy system. In other words, solar energy source is categorized by uncertainties and huge fluctuations which can impact adversely the system steadiness and consistency requiring batteries for energy storage. In general, hydro energy source provides high power, reliable in wet season and dries up in dry season while solar energy source is intermittent, and thus these types of energy sources are complementary for ensuring the 100 % availability of power supply in order to meet the load for the whole year. These complementary energy sources are sustainable, renewable, free and environmentally friendly. The proposed hybrid energy has been analysed using collected average data of available renewable energy sources and electrical demand. Based on the authors' practical experience, literature review and decision making methods via up-to-date advancement of using computer application and AI optimization techniques the potential of hybrid system has been evaluated, assessment criteria are summarized as follows: (Borkowski *et al*. 2021).

(i) The location of study has high potential of water flowing in the tributary during wet season and sufficient solar energy source for electricity generation. The energy sources are sustainable and complementary renewable energy sources (Mardani *et al*., 2015; Siksnelyte-Butkiene *et al*., 2020).

(i) For the reliability improvement and the cost minimization the requirement of the batteries. Solar and hydro energy sources are natural free sources and are also ecologically friendly and thus the hybrid power plant combining the ROR power system and solar PV is cost effective and sustainable. The configuration of the plant has been defined by the lowest NPC sources (Mardani *et al.*, 2015; Siksnelyte-Butkiene *et al*., 2020).

(ii) Generated power output of the run of over river scheme in optimal hybrid system was estimated using water flow rate, water head and fixed efficiency. In reality the dynamics of the hydrological situation always varies over time. Therefore, one of the drawbacks of this method is that it overestimates the actual generated power particularly run of the river systems in the with low water head due to the limitations of the turbine release, head and efficiency deviations sources (Mardani *et al.*, 2015; Siksnelyte-Butkiene *et al*., 2020).

(iii) Power capacities of solar PV and batteries have been estimated according to the monthly profiles of the stream flow, solar radiation and electrical load profile. The average water stream. Solar radiation data were directly obtained from NASA (NASA, 2019) on the monthly basis while batteries have been sized according to hourly characteristics for minimization of the hourly fluctuations of solar PV in day time sources (Mardani, Jusoh *et al*. 2015; Siksnelyte-Butkiene *et al.,* 2020).

(iv) Energy requirement was estimated based on rated power capacities of anticipated appliances and load profile was computed according to the socio-economic life and norms of the area of study. In the optimization processes of the proposed system it was assumed that generation capacity greater than the peak maximum to account for the power losses sources (Mardani *et al*., 2015; Siksnelyte-Butkiene *et al*., 2020).

7.5.2 Optimization Results of the Proposed System Using AI Algorithms

As it has been mentioned before, the average daily electricity consumption is 511. 1 kWh /day (Baseline), peak power capacity 30.31 kW, and load factor is 0.71. For the hybrid electric system to supply sufficient power to satisfy the load generated electricity should be equal or greater than the highest power capacity. The proposed system has been optimized when LEPP equals to zero denoting that no deficiency of power assuming hybrid energy system supplies power at 100%. Optimization results which are processed by AI techniques such as PSO, GWO and GWO-PSOHD algorithm show the reduction in total NPC and corresponding levelized COE in reference to soft computing method (HOMER application). Table 7.21 shows comparison of the optimization results of the soft computing and AI methods for the optimized MHPS/Solar PV/Batteries system (LEPP = 0). The AI techniques are implemented in MATLAB and optimal results are presented as follows:

7.5.2. 1 Results of PSO implementation

Among the above-named three AI optimization techniques, PSO method has indicated the greatest NPC after HOMER software. The PSO implementation gives accumulated NPC and its corresponding levelized COE which are \$ 92,472.82 and \$ 0.1182 /kWh respectively. These categories of financial standards are lower than in the PSO method than in the HOMER platform. The NPC and COE are more minimized nearly 67.3 %. It denotes that PSO method offers superior solution in terms of reduction of cost in comparison with HOMER software and although has greatest cost in comparison with those costs achieved by the GWO and GWO-PSOHD optimization techniques. Figure 7.16 describes the NPC optimization results for the MHPS/Solar PV/Batteries system using the PSO algorithm. Furthermore, Figure 7.17 illustrates COE optimization for the MHPS/Solar PV/Batteries system using PSO algorithm

7.5.2. 2 Results of GWO implementation

GWO implementation minimizes further accrued NPC and levelized COE of the proposed off-grid hybrid renewable energy-based system having the magnitudes which are less than that achieved from PSO method. The optimally designed system using GWO provides NPC and COE which are \$ 92,472.82 and \$ 0.11 82 /kWh respectively. These types of economic values are less than in the GWO technique than in the HOMER. Both NPC and COE are further reduced up to around 65 %. The GWO techniques offers intermediate cost between the PSO and GWO-PSOHD technique having reduce cost in comparison with HOMER software. Figure 7.17 depicts the NPC optimization results for the MHPS/Solar PV/Batteries system using GWO algorithm. Furthermore, Figure 7.21 illustrates COE optimization for the MHPS/Solar PV/Batteries system using GWO algorithm.

7.5.2. 3 Results of GWO-PSOHD implementation

The research of this paper has employed GWO-PSOHD algorithm to optimize the proposed of energy system. Similarly, this technique has been used to solve the formulated objective function of by the minimization of NPC. The number of iterations and population size are 100 and 50 respectively. Optimal results have indicated that the hybrid algorithm provides the least value of NPC in comparison with other aforementioned optimization methods. Both NPC and COE are more reduced up to about 64. 96 %. Figure 7.18 represent the NPC optimization results for the MHPS/Solar PV/Batteries system using GWO-PSOHD algorithm. Furthermore, Figure 7.22 illustrates COE optimization for the MHPS/Solar PV/Batteries system using the GWO-PSOHD algorithm. Figure 7.20 depicts COE optimization for the MHPS/Solar PV/Batteries system using PSO algorithm.

Table 7.21: Comparative analysis of optimization results of the soft computing and AI methods for the optimized MHPS/Solar PV/Batteries system (LEPP = 0)

Financial parameters	HOMER	PSO	GWO	GWO-PSOHD
NPC ($)	141 397.76	95 167.21	92 472. 82	91,854. 10
COE ($/kWh	0.1818	0.1185	0.1182	0. 1181

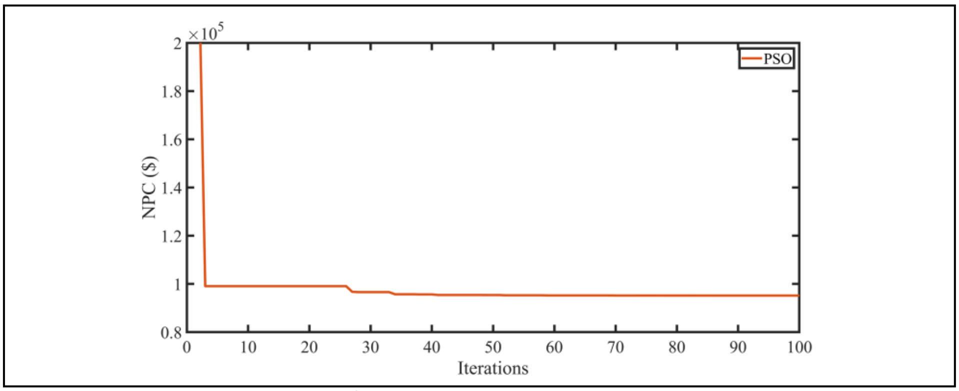


Figure 7.15. NPC optimization for the MHPS/Solar PV/Batteries system using PSO algorithm

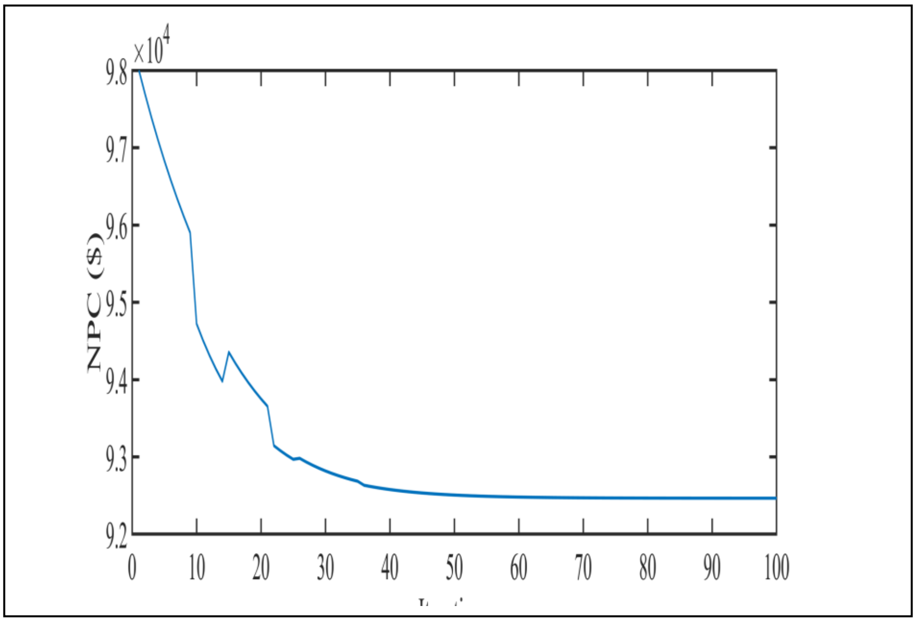


Figure 7.16. NPC optimization for the MHPS/Solar PV/Batteries system using GWO algorithm

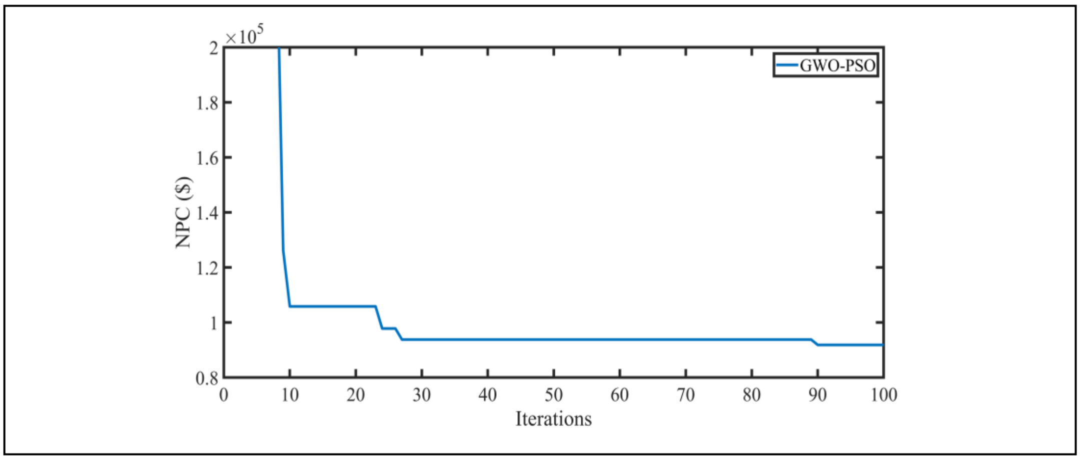


Figure 7.17. NPC optimization for the MHPS/Solar PV/Batteries system using GWO-PSOHD algorithm

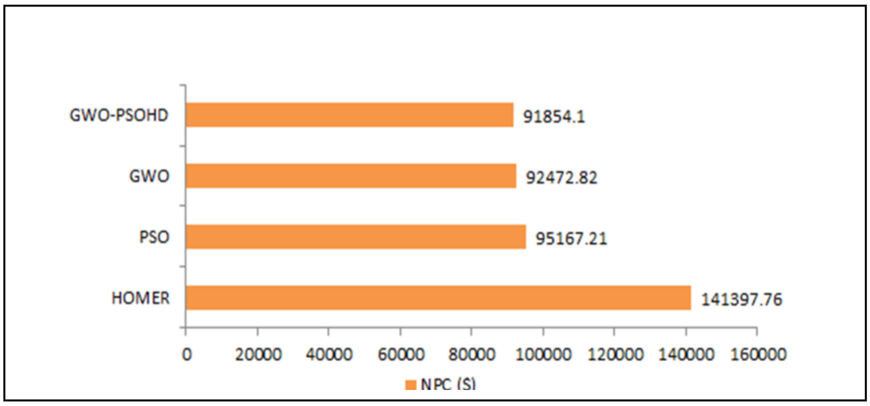


Figure 7.18. NPC for the MHPS/Solar PV/Batteries system by soft computing and AI methods

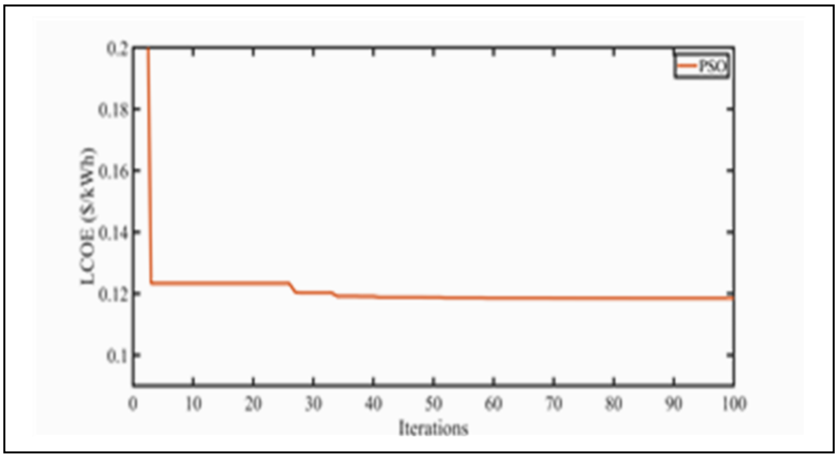


Figure 7.19. COE optimization for the MHPS/Solar PV/Batteries system using PSO

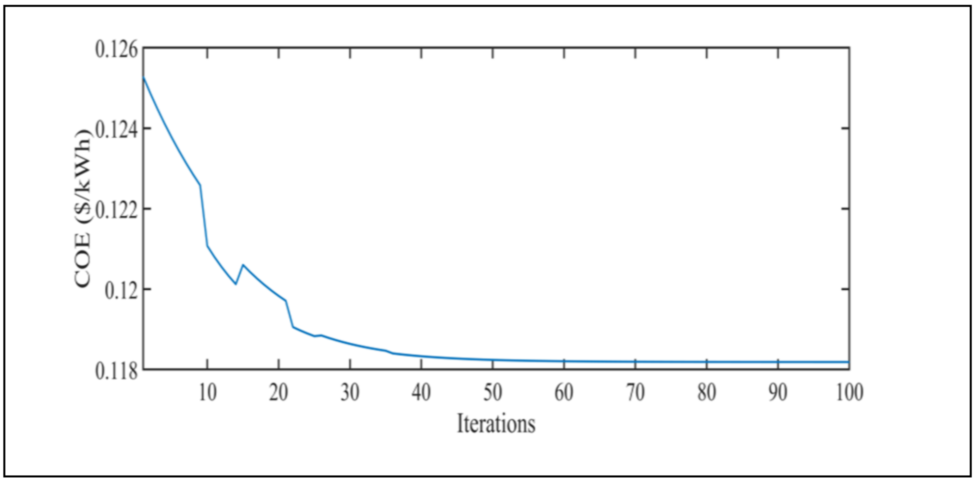


Figure 7.20. COE optimization for the MHPS/Solar PV/Batteries system using GWO algorithm

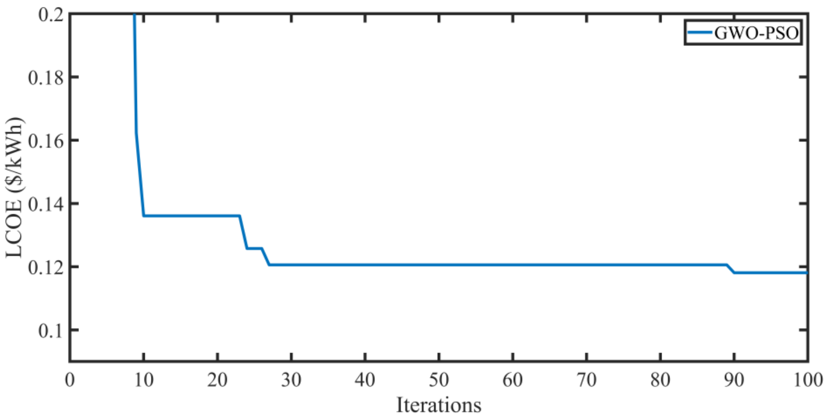


Figure 7.21. COE optimization for the MHPS/Solar PV/Batteries system using GWO-PSOHD algorithm

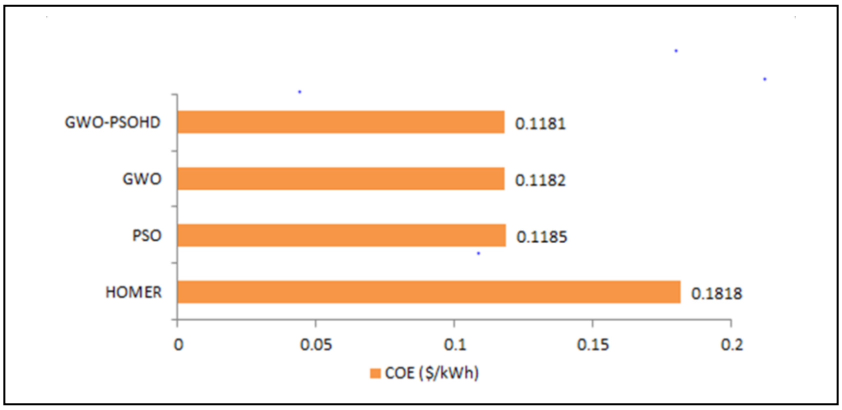


Figure 7.22. COE for the MHPS/Solar PV/Batteries system by soft computing and AI methods

Moreover, Figures 7.19 and 7.23 portray the total NPC and COE for the MHPS/Solar PV/Batteries system of the soft computing and AI optimization methods correspondingly. Table 7.21 illustrates the comparative analysis of the optimization results of the soft computing and AI methods for the optimized MHPS/Solar PV/Batteries system (LEPP = 0).

7.6 CONCLUSIONS, RECOMMENDATION FOR THE LONG-TERM SUSTAINABILITY OF THE TRIBUTARY UNDER STUDY, AND FUTURE RESEARCH WORK

Techno-economic analysis of unexploited potential of a non-perennial tributary incorporated with solar energy source and batteries has been carried out. A case study has been made at Ikata tributary located at Ikukwa village, Mbeya rural district, Mbeya region, Tanzania. The main objective is to examine the potential of using the unused tributary hybridized with solar photovoltaic and batteries to meet electrical load demand for small communities without connection to grid power network. Data for estimation of water flow rate and head for Ikata tributary have been achieved by direct measurement using traditional methods.

In the micro-hydro/solar photovoltaic/batteries system, MHPS immensely indicates high positive impact in terms of power output. The overall proposed hybrid energy system provides sufficient power which is mainly contributed by MHPS during extended period of rainy/winter season. Power capacity for MHPS in the hybrid energy system drops down to zero in the due to the limitation or absence water flow in dry period. Within this proposed hybrid energy system, SPVS with batteries provides electricity during rainy and dry seasons. However, SPVS with batteries enormously offers electricity during dry/summer seasons with limited or absence of power output from MHPS.

Three major implications can be made about this research work. First, the hydro energy source from the tributary has high abandoned potential of energy especially in the rural expanses with high and prolonged rainfall. Second, this proposed hybrid energy system is economically feasible with lowest total NPC and COE. Third, the optimal design of proposed hybrid system produced by AI optimization techniques (PSO, GWO, GWO-PSOHD) is more cost effective than that executed by soft computing technique (HOMER pro software). In the group of AI optimization approaches PSO technique has highest price while cost acquired by GWO-PSOHD technique is the lowest, and cost by GWO method lies between the two.

In the survey made by authors in the site of the project much deforestation was observed. Villagers get firewood for cooking food and heating purposes by cutting trees in Mbeya Mountains. The on-going deforestation should be stopped for achieving long term sustainability of Ikata tributary and other hydro energy sources (Kichonge, 2018; Drakenberg *et al*., 2016). The action of stopping the deforestation can also sustain the performance of MHPS in future.

In this study, traditional approach in direct measurements of power has been applied and used for the mathematical analysis of theoretical power of MHPS. Some of the parameters obtained by such approach, for instance, water flow rate has been used as a reference during simulation process by HOMER pro software. Therefore, in future the research can be furthered by improved methodological approaches including more modern AI methods while integrating other energy sources with the system under investigation. Detailed techno-economic feasibility analysis can be implemented using advanced methods of measuring techniques, geological survey and grid integration to support national power network from TANESCO. Also, this study can be expanded by implementing sensitivity analysis under the varied LEPP on the assumption that the hybrid renewable energy based system does not produce power at 100 %.

CHAPTER 8

CONCLUSIONS, RECOMMENDATIONS AND FUTURE RESEARCH WORKS

8.0 GENERAL

This chapter majorly provides the conclusions in the reflection of study's findings. Lack of electricity in rural areas in developing countries exists in almost all areas that need electricity services including housing, schools, health centers, village, agriculture, communications, mobile phone charging stations, food preparation etc. Therefore, the conclusions in this work are primarily summarized based on the heterogeneity nature as research approach by involving different analyses of techno-economic feasibilities of supplying electricity to proposed sites of research. These areas need to be comprehensively studied before implementing individual projects. Similarly, understanding the information about the technological and economic aspects of any designed system is paramount importance. The aim this approach is to broadly investigate techno-economic feasibilities of using renewable energy-based configurations with the potentials of available renewable energy resources within the area of study to effectively and efficiently address the energy shortage and environmental issues within the area of study. In other words, techno-economic analyses involve mainly hybrid renewable energy based systems for different applications such as typical rural house, rural house with electrical power requirement for small irrigated plot for peasant's residence and two villages of Simboya and Ikukwa in Mbeya rural district, Mbeya region, Tanzania.

HOMER pro software and AI optimization techniques platforms have used in the research work. Optimal configurations of renewable energy based systems (Single and hybrid micro-grid systems) have determined using the lowest total NPC and LCOE have been used in the study. A recapitulation of the key results, conclusions of the research, recommendations and future research are presented in the next sections of this chapter.

8.1 RECAPITULATION OF THE KEY RESULTS

The main goal of this study is to execute the techno-economic analysis of renewable energy based micro grid systems for rural applications in Tanzanian environment. The study has been carried out by investigating different renewable energy based systems for feasibilities of supplying electricity to various applications. The study has implemented by including single and multiple (hybrid) renewable energy systems. Standalone systems with single sources which have analyzed are SPV and SWTES systems. However, basically this research work involves the techno-economic feasibilities for off-grid HRESS's specifically for Simboya village in Tanzania. These off-grid HRESS's are generally SPV based systems due to the high potential and broad coverage of sunlight in most parts of the country being located closer to equator. Also, in consistent with the main goal and specific objectives of the research, here is the list of modelling and optimization of different configurations of renewable energy based system expected to supply electricity to different selected sites of rural areas of Tanzania:

I. Techno-economic feasibility analysis Standalone SPV system with battery energy storage system (Presented in Chapter 3). HOMER software and PSO technique platforms have been employed in the analysis. Comparative analysis between standalone SPV system with battery energy storage and decentralized DG has been executed. In addition, SWOT analysis has been used to investigate the Strengths, Weaknesses, Opportunities, and Weaknesses about the deployment of SPV systems in Tanzania. Finally, recommendations are provided to enhance the utilization of high potential of solar energy through SPV systems in a country.

II. Techno-economic analysis of a SWTES (Small Wind Turbine Electric System) for both small irrigated farming and power supply to a domestic rural house located in Simboya village in Tanzania (Presented in Chapter 4). HOMER software platform has been used for simulation of SWTES.

III. Techno-economic study of a hybrid SPV/Biogas generator/battery energy storage system that is expected to supply electric power to an entire Simboya community, Tanzania (Presented in Chapter 5). In the analysis of system reliability has been taken into consideration using LEPP and optimal capacity of battery systems using AI optimization techniques. HOMER pro software and GWO technique platforms have been used to investigate the system.

IV. Techno-economic analysis of an energy storage management system by taking into account the configuration of a hybrid SPV-Hydro-Biogas-Battery bank system that is also expected to generate electricity for Simboya village in Tanzania (Presented in Chapter 6). HOMER pro platform for simulation purposes.

V. Techno-economic analysis of a freestanding solar PV/Small hydro/Battery energy system predicted to supply electricity Ikukwa village in Tanzania (Presented in Chapter 7). Similarly as in Chapter 5, the analysis of system reliability has been taken into consideration using LEPP and optimal capacity of battery systems using AI optimization techniques HOMER pro software and the AI optimization techniques (PSO, GWO, GWO - PSO hybrid platforms have been used.

The results of modelling and optimization demonstrate renewable energy-based systems of above described configurations. All above named viable configuration provide ideal solutions in terms of electricity generation, GHG emissions, and price. This method of power generation could be a solution for Tanzania's distant, cities and towns where the power grid is unreliable associated with extended outages and frequent power shedding. Based on the list of the configurations I**, II. III, IV and V** corresponding chapters from Chapter 3 to Chapter 7 as provided in brackets) key findings are recapitulated chapter wise as follows:

8.1.1 Key Results of Configuration I as per Chapter 3

This part of the chapter 8, presents the main results of techno-economic feasibility analysis regarding standalone SPV system with battery energy storage system (as presented in Chapter 3). The analysis is performed to investigate the viability of supplying electricity to a typical rural housed located at Simboya village, Tanzania. In this analysis, absolute NPC's autonomous SPV framework (Scenario 1) and DG set (Scenario 2) are $ 2089 and $ 19 488 individually. In the situation 1 (Solar with battery capacity), absolute COE in the HOMER software and PSO approach are $ 0.397/kWh and $ 0.27/kWh $ individually. In Scenario 2 (DG), absolute COE got by HOMER pro software and PSO method are $ 3.71/kWh and 2.57 $/kWh individually. Moreover, after effects of the two situations 1& 2 and advancement strategies show that there is a drop altogether COE in the PSO procedure for somewhere close to 69 %.

8.1.2 Key Results of Configuration II as per Chapter 4

This part of this chapter 8, presents the main results of techno-economic feasibility analysis regarding analysis of a SWTES (Small Wind Turbine Electric System) for both small irrigated farming and power supply to a domestic rural house located in Simboya village in Tanzania (As presented in Chapter 4). The generation of power from wind energy systems is governed by a range of factors, including wind resource capacity as well as technical and functional concerns. In this study, SWTES was created with the wind resource pattern at the rural site in mind. The economic and technological feasibility of proposed off-grid SWTES for multiple electricity demands of a peasant residence in rural Tanzania was evaluated. The modelled SWTES is intended to both power and water supplies to rural household and agricultural applications. Because of the high demand for water supplies, particularly irrigation, power consumption is higher during the dry periods than during the rainy periods. Key findings are summarized as follows:

During the dry season, the load profile was used to design SWTES. The deferred load of the pumping system was linked with the electrical equipment in this study to generate the main load. The highest load and daily utilisation are estimated to be 1.48 kW and 11.26 kWh/day, respectively. The capacity is greater than the largest power for acceptable CF simulated SWTES. It includes a WT ranging from 1 to 10 kW, a 10 k W converter, and 4608 batteries. The fluctuating nature of wind power resources, on the other hand, is a major drawback of this system.

The use of off-grid SWTES demands a large number of batteries, which drives up the price. The duration of this project has been set at 25 years. The NPC and LCOE are $106 273.80 and $ 1.58/ kWh, respectively. In fact, SWTES is cheaper than grid extension. SWTES becomes more viable after the BGE of 4.58 km is reached.

8.1.3 Key Results of Configuration III as per Chapter 5

The HOMER and GWO methods were used in this work to obtain the techno-economic analysis of the optimal design of a SPV-BIOG-BATTERY hybrid system for delivering power to Simboya hamlet in Mbeya rural district, Mbeya region, Tanzania. According to the used methods the key results in this section are of two groups. First group is the presentation of the key results obtained in the HOMER platform while the second group is the presentation of the key results in GWO platform.

(a) Key results obtained in the HOMER platform: In this part of this study, the ideal configuration of the off-grid HRESS system components is a 40 kW PV, 25 kW BIOG, 144 Generic1 kWh Li-ion batteries, four in series with 36 strings of system bus voltage 24V, and a 40 kW converter with a cycle charging dispatch method. A negative distance number indicates that the LCOE of an off-grid micro power system is always less than that of grid expansion, whereas a positive distance value indicates that the LCOE of an off–grid system is less than that of grid expansion beyond that distance. Grid extension (EDL) is less expensive than HRESS below this break-even distance and is not financially feasible beyond this distance. The breakeven BGE in Scenario 1 is 0.19 km, with NPC and LCOE of \$106,383.50 and \$ 0.1109/kWh, respectively. Sensitivity analysis shows that increasing yearly scaled solar radiation from 6.11 kWh/m^2/day to 7.5 kWh/m2/day at constant biomass feedstock and electrical load minimizes the optimized system's total NPC, LCOE, and operating cost. The overall NPC, LCOE, and operating costs of the suggested ideal off-grid hybrid SPV/BIOG/BATTERY are \$ 106,383.50, \$ 0.1109/kWh, and \$ 1755.95, respectively, which are lowered to \$ 101,584, \$ 0.106/kWh, and \$1454. Environmentally, the proposed optimal off-grid HRESS, that is, scenario 1 (SPV/BIOG/BB) emits the least carbon dioxide (CO2) around 0.531 kg/year in comparison of other scenario 2 (DG/BIOG/BB) with CO2 emissions equivalent of 67 461 kg/year and conventional DG (Scenario 3) discharging CO2 around 635 966 kg/year.

(b) Key results obtained in the GWO platform: The off-grid HRESS has been optimised when LEPP equals 0, indicating that there is no power shortage. In other words, the supply of generated electricity and the demand for energy are properly balanced. The GWO method study of the optimised system reveals that the overall NPC and LCOE are \$ 85, 106 A, and \$ 0.0887/kWh, respectively. When compared to soft computing tools (HOMER), the adoption of AI optimization approach (GWO) has further reduced the financial metrics of power generation by roughly 20%.

The GWO method is used by taking into account the planned system's unbalanced situation. In this study paper, LEPP is regarded as the sensitivity variable, and thus the analysis of the optimised system has been analyzed based on the fluctuation in estimated magnitudes of LEPP, namely 0. 04 and 0. 06. When LEPP = 0.04, the setup of off-grid HRESS displays an overall NPC of \$ 79 545.992 and an LCOE of \$ 0.0316/kWh. When LEPP equals zero, the variance in overall NPC of the intended off-grid HRESS has become smaller than that of the balanced energy system. The decrease in excess power can be attributed to a decrease in the capacity of the solar PV array.

Similarly, when LEPP equals 0.06, off-grid HRESS setup has an overall NPC of \$ 71747.36 and an LCOE of \$ 0.0102/kWh. It means that at a certain LEPP of 0.06, the overall NPC of ideal HRESS is reduced by at least 20% when compared to the balanced situation of generation capacity and energy needs.

8.1.4 Key Results of Configuration IV as per Chapter 6

Techno-economic analysis of an energy storage management system by taking into account the configuration of a hybrid SPV-Hydro-Biogas-Battery bank system that is also expected to generate electricity for Simboya village in Tanzania (Presented in Chapter 6). The most expensive component is biogas; after that, the majority of capital investment is spent on batteries, followed by SPV system. Actually, hydro energy is less volatile than solar PV systems, and its lifetime is estimated to be 75 years (3 times the lifecycle of a solar panel or project). Hydro power has the largest share of all renewable energy sources composing the off-grid HERSS in order to achieve maximum reliability with the incorporation of a battery bank. The most expensive unit is biogas; the expensive component is biogas, followed by battery bank. In comparison of both solar and biomass energy sources, the hydro energy system has the lowest NPC. The main findings regarding the optimal system components, control strategies, total NPC and LCOE are presented in Table 8.1 Key optimal results of proposed of SPV-Hydro-Biogas-Battery bank system.

Table 8. 1: Key optimal results of proposed of SPV-Hydro-Biogas-Battery bank system

System	Bio (kW)	PV (kW)	Hydro (kW)	Battery (QTY)	Converter (kW)	Dispatch (CC/LF)	RF	NPC ($)	LCOE ($/kWh)
HRESS	10	30	85.1	48	20	CC	100	77861.88	0.08117
DG	--	--	--	--	--	CC	0	1824076.00	1.90

The specified area of study has an annual solar radiation average of 6.11 kWh/m^2/day. The annual sunlight has ranged from 4 to 8 kWh/m^2/day. The variance of solar irradiance in the stated range, the NPC, and CO_2 emissions decreased from $77, 861. 88 to $73, 968.77 and 9. 29 kg/year to 7. 09 kg/year, respectively.

Influence of biomass/biogas volatility on system operation by adjusting the biomass/biogas fuel cost between $ 0.25/tonne and $8/tonne. In fact, when the cost of biomass/biogas fuel increased from the previously specified range, CO_2 emissions decreased from 9. 29 kg/year to 6 kg/year NPC increased from $ 77, 861 to $ 55 kg/year. 88 to 106,300.4. In general, findings relating to an increase in the price of biomass/biogas fuel may inhibit the use of biomass/biogas powered generators (Increased operating cost). Proposed approach of power generation can minimize carbon emissions by 99 percent to 100 percent. For example, DG can emit around 52680 kg of CO_2 per year, whereas its off-grid counterpart HRESS can emit the same amount of CO_2 (9.29 kg/yr).

8.1.5 Key Results of Configuration V as per Chapter 7

Techno-economic plausibility analysis is carried out for improving access to electricity for small communities in Ikukwa village, Mbeya rural district, Tanzania. This location is made up of a non-perennial tributary called Ikata, whose water flow originates in the highlands surrounding Mount Mbeya's peak. In this feasibility study, a case study is conducted at the Ikata tributary, which uses its non-perennial hydro power source to maximize hybrid micro-hydro-solar PV. This study's analysis has been executed in two platforms. The Hybrid Optimization of Multiple Energy Resources (HOMER) pro programme is used for techno-economic analysis in order to determine the best configuration for the proposed hybrid system. The article also includes applications of AI techniques like as PSO, GWO, and GWO-PSOHD algorithms for designing off-grid systems, which reduce NPC and COE further. Similarly, in the study, the system is optimised by taking system reliability into account. The hybrid GWO-PSO performs outstandingly economically as it gives lowest generation charge among the other platforms which have been in this specific research work. Results in both soft computing tool (HOMER pro software) and AI optimization techniques (PSO, GWO, and GWO-PSO) are re-emphasized in Table 8.2 summarizes Comparison of soft computing and AI optimization outcomes for the optimised MHPS/Solar PV/Batteries system (LEPP = 0).

Table 8.2: Comparison of soft computing and AI optimization findings for the optimized MHPS/Solar PV/Batteries system (LEPP = 0)

Fiscal parameters	HOMER	PSO	GWO	GWO-PSOHD
NPC ($)	141 397.76	95 167.21	92 472. 82	91,854. 10
COE ($/kWh	0.1818	0.1185	0.1182	0. 1181

In general, based on the optimal results of given configurations are cost effective and environmentally friendly. AI optimization techniques have indicated better economic performance.

8.2 CONCLUSIONS OF THE STUDY

This particular section of this chapter describes the conclusions of this study starting from the Chapter 1 to the Chapter 7. The conclusions of individual chapters are described as follows:

8.2.1 Conclusion as per Chapter 1

Energy is extremely important in our daily lives for socioeconomic development. The degree of energy consumption is directly linked to a country's economic progress. Developed countries often consume more energy than developing countries. Energy poverty is a major concern in developing countries, particularly in the SSA region. Furthermore, the concept of managing energy shortages with conventional energy sources is unpopular because they are expensive, insecure, depletive, and polluting.

Non-conventional energy sources (renewable) can be used to address the issue of energy scarcity and negative environmental repercussions. Renewable energy sources are advantageous since they are replenished, sustainable, secure (provide energy security), and environmentally friendly. Similarly, grid extension is costly in terms of transmitting and distributing power from district power to remote off-grid regions. In most situations, developing-country power systems are unreliable, with frequent outages and shedding. As a result, decentralized renewable energy-based systems can be utilized to enhance the access to modern energy services, including electricity particularly in off-grid areas of developing countries. Furthermore, the deployment of local decentralized renewable energy-based systems is beneficial for contributing to global efforts to reduce harmful emissions from fossilized energy systems.

Knowing the technical and economic factors is compulsory for the system's reliable and attractive economic performance. As a result, a techno-economic feasibility analysis of the system is performed prior to the deployment of a renewable energy-based system that is projected to supply power to a specific off-grid location.

8.2.2 Conclusion as per Chapter 2

The presentation of this Chapter 2 begins with a description of preliminary themes with the goal of emphasising critical features of constructing decentralized renewable energy-based systems for rural electrification. The use of renewable power sources not only solves the energy demand issue in most of the rural areas of developing countries including Tanzania but also address the environmental concerns emanated from using fossil fuels in energy production. The second section discusses the state of the art, issue statements, and research gaps. In the light of the reviewed literature, the following research gaps were identified.

- The potential/weather statistics and pricing of renewable energy sources vary by location. Power generation from renewable energy sources necessitates a feasibility analysis.
- There are numerous commercial and non-commercial HRESS models for rural electrification, with a limited number of micro hydro-based power systems and village electrification models (Also, rural domestic house models).
- There have been numerous researches on the design and development of decentralized HRESS in rural areas that lack adequate optimization approaches due to the intermittent nature of renewable sources.
- The Use of artificial intelligence (AI) approaches for sizing and modelling of a hybrid renewable energy system for selected site electrification is a new trend of researches.
- The employment of electronic equipment and intermittent nature of renewable energy sources in the design and development of HRESS results in power quality issues including voltage instability (Reliability).

The research problem has been formulated and it has been described in this Chapter 2. Due to the intermittent nature of renewable energy sources, Hybrid renewable based system is considered suitable. Any hybrid renewable-based system should be designed in a way that is both technically and economically sound. However, the process of building a hybrid renewable energy based systems for cost effectiveness and reliability is complicated because it incorporates different energy sources with varied characteristics. Furthermore, only few researches have been provided on the integration of renewable energy sources in autonomous remote rural micro grids. The proposed research project's goal is to conduct a techno-economic analysis of renewable energy-based systems (Single source or Hybrid power sources) for rural applications.

8.2.3 Conclusion as per Chapter 3

It should be re-stated that Chapter 3 presents the standalone solar PV (SPV) techno-economic feasibility analysis with battery energy storage system. In this subject, HOMER and PSO technique research platforms have been used. The analysis has revealed that standalone SPV is more cost-effective and dirty free energy source with respect to DG. DG use fossil fuels (diesel) which are expensive and pollutant. Also, PSO technique performs better economically (PSO techniques has demonstrated the reduction in cost of power generation) than HOMER software platform.

8.2.4 Conclusion as per Chapter 4

It should be reaffirmed that the Chapter 4 provides the techno-economic analysis of a SWTES (Small Wind Turbine Electric System) for both small irrigated farming and power supply to a domestic rural house in Tanzania. The analysis has been executed in HOMER software platform so as to obtain optimal configuration of the proposed SWTES. The use of off-grid SWTES demands a large number of batteries for improving the system reliability which in turn it elevates the price. However, SWTES is less expensive than grid extension.

8.2.5 Conclusion as per Chapter 5

It should be mentioned again that Chapter 5 offers the techno-economic feasibility analysis of an amalgamated solar photovoltaic (SPV)/Biogas/Battery banks system anticipated to supply power to Simboya village, Mbeya rural district, Tanzania. In this specific analysis both soft computing tool (HOMER pro software) and AI optimization technique (GWO) have been utilized in the design of proposed off-grid HRESS. Hybrid SPV)/Biogas/Battery bank system is cheaper than the grid extension. In addition, GWO technique has indicated the improved financial performance than HOMER pro software.

8.2.6 Conclusion as per Chapter 6

It should be recapped that Chapter 6 gives the techno-economic feasibility analysis of a hybrid SPV-Hydro-Biogas-Battery bank system for Simboya village in Tanzania. In the light of used renewable energy sources and energy demand, the chapter is almost an extension of the preceding Chapter 5 with an incorporation of hydro power source (seasonal tributary) found in the neighbouring village called Ikukwa village. HOMER platform has been used for simulation purposes. In the analysis of the proposed hybrid SPV-Hydro-Biogas-Battery bank system for supplying electricity to the selected site of study, hydro power source has been assumed to be close to the proposed site of study. Out of the three renewable energy sources constituting the proposed off-grid HRESS, hydro energy source has highest penetration of the threes sources for the reason that has the least volatility and extended lifespan (three times of the whole project lifetime). Biogas power generating unit has highest total NPC followed by that of batteries, SPV power source, and hydro power sources. Generally, it can be concluded that the proposed optimal HRESS is cost-effective and environmentally friendly. The system has a potential of mitigating carbon dioxide ranges from at least 99 to 100 % with respect to equivalent standalone DG system. However, biogas fuelled generator system has high cost but can be further reduced by the increased penetration levels of solar PV and hydro power energy source.

8.2.7 Conclusion as per Chapter 7

Chapter 7 presents the intelligent technique development and implementation for modelling and sizing hybrid renewable energy based micro grid system. The system incorporates solar and hydro sources. The batteries are also included to solve the challenge of variability of solar and hydro energy sources (Seasonal tributary). Therefore, techno-economic analysis of hybrid SPV/Hydro/ battery bank system has been implemented and is expected to provide electricity services to Ikukwa village in Mbeya rural areas, Tanzania. Both soft computing tool (HOMER pro software) and AI optimization methods (Single and hybrid metaheuristic methods) have been used for the analysis. The system proposed off-grid HRESS is cost effective and more financially feasible in comparison with grid extension. Used metaheuristic are PSO, GWO and hybrid PSO-GWO. The analysis has taken into account the system reliability. Among the soft computing and the nature inspired three methods, hybrid PSO-GWO has indicated the most superiority of all in terms total NPC plus corresponding LCOE.

8.3 RECOMMENDATIONS AND FUTURE RESEARCH WORKS

Subsequent to the presentation of the main findings and conclusions of the study, in this chapter the study is accomplished by delivering the general recommendations and outline on future research works.

8.3. 1 General Recommendations

Here are general recommendations and outlines regarding the future research works:

- The analyses of this research involve different proposed decentralized renewable energy based systems for various applications. The analyses do not employ real- time data approach, and thus future research should be analysed using real-time data applications.
- Power generated from renewable energy based systems is full of uncertainties and fluctuations. Apart from employed ordinary methods of addressing intermittent nature of renewable energy sources such as deployment of battery energy storage, backup systems and hybridization of energy sources, the use of artificial intelligent control strategies for the improvement of the system performance of the energy systems is highly recommended.
- Full coverage of this particular study embroils the decentralized off-grid hybrid renewable energy based systems. These decentralized off-grid systems require large amount of batteries for storing energy. Therefore, cost minimization due to the high requirement of batteries in such systems is compulsory. In the forthcoming research, the analysis of the systems should include other sources like grid power network for the cost minimization of the batteries.

- More researches are required for getting the appropriate local business models for different rural power applications in developing countries particularly in the African continent in SSA region and the rest parts of the world of similar conditions.
- In this study, low levels of AI optimization procedures are hybridized. For the improvement of performance future researchers may further apply high level hybridization techniques

8.3. 2 Future Research Works

Future research works are concisely re-explained chapter by chapter based on the list of configurations **I, II, III, IV, and V** (corresponding chapters from Chapter 3 to Chapter 7 as provided in brackets):

- Chapter 3 presents the techno-economic feasibility analysis Standalone SPV system with battery energy storage system (In this study has been represented as configuration **I**). In future studies, the current system of standalone SPV systems and DG can be integrated, and techno-economic performance evaluation can be conducted utilizing a real-time method and/or AI optimization algorithms.
- Chapter 4 provides techno-economic viability investigation of a SWTES (Small Wind Turbine Electric System) in Tanzania for both small irrigated farming and electricity supply to a household rural dwelling (Configuration **II**). Presently, the optimization analysis is implemented in HOMER platform. However, in the future, the study could be improved by analysing the integration of other energy sources, such as grid electricity, and by employing AI optimization approaches.
- Chapter 5 discusses the techno-economic analysis of an autonomous hybrid SPV/Biogas generator/battery energy storage system that is projected to deliver electricity to the entire Simboya village in Tanzania (Configuration **III**).The examination of optimal off-grid HRESS reliability has been taken into account the use of LEPP, as well as the ideal capacity of rechargeable batteries utilizing AI optimization approaches. The system was investigated using both HOMER pro software and GWO approach platforms. In the future, the ideal off- grid HRESS can be enhanced by interconnecting the system with other power sources and storage energy systems, and further studied utilising sophisticated approaches such as metaheuristic methodologies to build up an enhanced body of knowledge regarding optimization problem solutions.
- Chapter 6 offers the presentation of the techno-economic feasibility analysis of an integrated SPV-Hydro-Biogas-Battery bank system that will also provide power for

Simboya community in Tanzania (Configuration **IV**). In this current study, hydro power source is actually originated from the River Shongo which is found at neighbouring known as Ikukwa village. However, in this topic the hydro power is assumed to be close to the Simboya village in consistent with the definition of distributed power generation being situated near the point of power application. Hydro energy source has the least variability in comparison with solar and is cost-effective as well, (biogas powered unit is the most expensive within the off-grid HRESS). For an improved reliability and cost reduction, the optimized HRESS includes the highest penetration of hydro power source and batteries. The modelling and optimization of the system has been implemented in HOMER platform. In the future, such off-grid HRESS can be developed by incorporating with other sources, like as the grid, and optimizing using advanced AI algorithms.

- Chapter 7 explains the techno-economic viability analysis of an autonomous integrated PV/small hydro/battery energy system that is expected to supply electricity to the Tanzanian village of Ikukwa (Configuration **V)**. As per Chapter 5, the examination of system reliability was performed using LEPP, and the optimal capacity of battery systems was determined using AI optimization techniques HOMER pro software and the AI optimization techniques (PSO, GWO, GWO - PSO hybrid platforms). In future the analysis can be extended by including modified or high level of hybridization.

As it has been stated from the beginning of this study, high energy demand particularly in developing countries like Tanzania and the mitigation of harmful emissions worldwide can be addressed through the utilization of local renewable energy based systems. In addition, in the premises connected to the unreliable grids especially in rural areas of developing countries, decentralized renewable energy systems are also the best options. Nonetheless, the main concern of these energy sources, particularly solar and wind power resources is their intermittent nature causing complete periodical absence or variability of power outputs. The intermittency of renewable energy sources necessitates the use of batteries thus incurring additional cost. Apart from employing energy storage systems mostly batteries, hybridization by complementary energy sources is imperative for overcoming the negative effects of intermittency. Therefore, hybrid energy – based micro grid systems are deemed suitable for acquiring an improved reliability. In addition, tapping the benefit of high potential due to country's location near the equator, thus in this study all systems except (standalone SPV and SWTES systems) are solar energy-based systems because all optimal configurations consist of solar energy source. Consideration of both technological and economic aspects is crucial for any designing of any energy system. Similarly, hybrid energy-based micro grid systems contain multiple energy sources and their integration is complicated. They need the techno-economic feasibility studies for getting reliable, available and affordable electricity. HOMER platform is widely used for modeling and optimizing hybrid renewable energy based systems. Modelling and optimization of energy systems by AI methods provide appreciable results by giving lower energy generation costs. The AI methods are also capable of evaluating the system reliability and effective energy management of the off-grid HRESS including the appropriate management of battery.

LIST OF PUBLICATIONS

List of Papers (s) Published in Peer Reviewed Referred International Journals

1. I.J. Mwakitalima, M. Rizwan, and N. Kumar, "Standalone solar photovoltaic electricity supply to rural household in Tanzania," IETE Journal of Research, pp. 1-16, May, 2021, doi.org/10.1080/03772063.2021.1920854.

   [Impact Factor: 2.333, (SCI Indexed)]

2. I.J. Mwakitalima, M. Rizwan, and N. Kumar, "Potential of a non-perennial tributary integrated with solar energy for rural electrification: A case study of Ikukwa village in Tanzania," Journal of Mathematical Problems in Engineering, vol. 2022, Article ID 1172050, 37 pages, https://doi.org/10.1155/2022/1172050.

   [Impact Factor: 1.430 (SCI Indexed)]

3. I.J. Mwakitalima, M. Rizwan, and N. Kumar, "Opportunities and challenges in the development of smart cities in Tanzania. Advances in Energy Research, 7(2), 135-146, 2020, doi.org/10.12989/eri.2020.7.2.135.

   [Scopus Indexed]

List of Paper(s) Published in Peer Reviewed International Conference

1. I.J. Mwakitalima, M. Rizwan, and N. Kumar, "Feasibility Analysis of Solar Photovoltaic Based Distributed Power Generating System for Rural Areas of Tanzania," Studies in Indian Place Names (UGC Care Journal), JTACON2020, February 16-16, 2020,"

   [Scopus Indexed]

2. I.J. Mwakitalima, M. Rizwan, and N. Kumar, "Design of Small Wind Turbine Electric System for Household Electricity and Water Supply for Irrigation in Rural Tanzania (17 th IEEE Indicon 2020, Delhi Section, December 11-13, 2020; IEEE Xplore

. **[Scopus Indexed].**

List of Prospective Papers (s) in Peer Reviewed Referred International Journals

(i) I.J. Mwakitalima, M. Rizwan, and N. Kumar, “Integrating solar photovoltaic power source and biogas energy-based systems for increasing access to electricity in rural areas of Tanzania," International Journal of Photoenergy (Submitted the revised paper manuscript on 26/2/2022, **ID NO. 7950699)**

(ii) I.J. Mwakitalima, M. Rizwan, and N. Kumar, “Reliability improvement and optimization of SPV-hydro-biogas -battery bank system via highest hydro energy source penetration for Simboya village in Tanzania”: application of homer platform

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