ENERGY SUPPLY OPTIMIZATION OF THE MICROGRIDS. A CASE OF WASINI ISLAND

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Abstract

The energy transition topic from fossil fuel to non-fossil fuel and non-energy efficient appliances to energy efficient appliances has been gaining momentum since the realization that human socio-economic activities form the major catalyst to climate change. It is therefore clear that conventional power generation sources can hold rapid growth of technological innovations that are putting more pressure on the existing regimes. The pressures put on existing regimes have resulted to innovations of microgrids that uses variable power generation sources from solar and wind to cushion rural communities who are likely to defer their electricity connection due to the rush of providing charging stations for plug in electric hybrid vehicle and EV, also use of cleaning cooking relying on the National grid which has a reserve of only 1100MW.

This study looked at the essence of reliable and sustainable microgrids for rural areas such as the case study area. The island of Mkwiro - Wasini is not connected to the national electricity grid and its future access to electricity cannot be immediate. The study identifies multisource hybrid power supply systems that represent the use of renewable technology.

In this study wind turbine generators, solar photovoltaic panels, tidal wave energy converters and storage batteries were used to build a block chain microgrid that is optimal based on the performance criteria in terms of cost and reliability. In this study, an energy supply model was designed and simulated using MATLAB 2016a as platform for particle swarm optimization(PSO) algorithm. The algorithm was simulated to generate an annualized system cost and energy index reliability of non-dominated solutions. Three energy supply models were designed to find the best configurations using particle swarm optimization technique.

The intermittent nature of wind speed and solar insolation together with random load variation, a time series models were adopted to reflect the stochastic nature. A robustness and reliability test was conducted to determine the impacts of intermittent sources in the microgrid universal performance.

Keywords:

Energy Reliability, Microgrids, Particle swarm Optimization, wind generators, solar photovoltaic, tidal wave energy converters, annualized system cost and energy index reliability.

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Declaration

I do hereby confirm that the works presented in this proposal represent the author's original works and that the work has never been used for academic purposes in any university.

Admission number: **148463** signatures date:

Supervisor

I Dr. Kennedy Ronoh do hereby confirm that, the work is presented for examination with my approval

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Dedication

This dissertation is dedicated to the memory of my father who lived not to see the light of this day and become part of this great achievement. History states that, he lived well and died before witnessing part of his recreation and therefore today I live, and act based on his belief and copy his candid critical thinking in problem solving.

I also dedicate this work to my wife, Agnes Mbodze , my beloved mother, Priscilla Mbeyu Chiro , my three children, Tabu Mbeyu Kambu, Tarshish Chiro Kambu, and Deborah Mkambe Kambu for being patient with me and for the great support they provided as I was working on this research.

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Above all, I acknowledge the creator of universe who designed everything pretty and into its place hence declared good for human habitation and more importantly, He has declared a war with those destroying the earth.

List of Abbreviations/Acronyms

Abbreviation	**Full name**
ABC	Anti-bee colony
ASC	Annualized system cost
BESS	Battery storage system
CBO	Community based organization
ESM	Energy supply model
EENS	Expected energy not served
EIR	Energy index reliability
HOMER	Hybrid optimization model for electric renewables
LoadProGen	Load profile generator
LCOE	Least cost of energy
LSPS	Loss of supply probability
NPC	Net present cost
NCAP	National cooling action plan
NDC	National determined contribution
PSO	Particle swarm optimization
PV	Photovoltaic
PVGIS	Photovoltaic geographic information system
REopt	Renewable energy integration and optimization
RES	Renewable energy sources
TW	Tidal wave

SDG	Sustainable development goals.
SHS	Solar home systems
VNS	Variable Neighborhood Search
WT	Wind turbine
WEC	Wave energy converter

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Chapter 1: Introduction

1.1 Background of the Study

The Kenyan electricity demand is faced with high fluctuations due to bad weather, equipment failures, supply shortfalls, aging infrastructure, regular service interruptions for maintenance repair work causing non-scheduled blackouts that results to equipment destruction both to the industry and residential customers. The electricity connectivity to Kenyan grid stands at 75% with those having access meaning 25% still are yet to connected. As of 2021 the installed capacity was at 3077 MW, with 89 % of the generation from renewable energy such geothermal, wind, hydro, and some utility scale solar and an off-peak demand of 1,100MW(*About 18m People without Electricity - Report*, n.d.).

Kenya is faced with meeting international goals and commitments, in contributing towards net zero carbon emissions set in the National determined contributions (NDC) and National cooling action plan (NCAP) in ensuring paying its international debt of 2℃ debt by 2045. The explosion of modern cooking technology to safeguard the populations from congested chest and respiratory related diseases and save the planet from global warming temperature due traditional charcoal cookstove that encourages deforestations. The Kenyan grid is yet again facing an eminent constraint though still nascent, the growth of electrical vehicles and motorcycles from 350 in 2018 to the projected increase of 53,800 by 2040(Richardson, 2019). This can lead to a possibility of carbonizing the national grid and therefore delay remote communities with national grid connections.

6.7 per cent of people in rural Kenya had access to electricity compared to 58.2 per cent in urban areas in 2019(*Africa Energy Outlook 2019*, 2019) . The key highlights of Kenya's Rural Electrification Fund (2018), charges all electricity consumers 5 per cent of the value of their monthly electricity consumption towards electrification(*Kenya-National-Electrification-Strategy-KNES-Key-Highlights-2018.Pdf*, n.d.) According to the light global report (2023),Mkwiro island has an area of 4.84(km sq) sparsely populated and undeveloped, with a household of 295 and a population of 1637 (*Off-Grid Energy Has Key Role in Kenya's New Electrification Strategy | Lighting Global*, n.d.). The island has a high rate of infant mortality pointing to the higher rate of poverty (Chaigneau T, Brown K, Coulthard S, Daw TM, Szaboova L. 2019). The island is not connected to the national grid and the community majorly depends on solar home systems appliances and paraffin which are no longer sustainable because of their short life span.

The Island of wasini and Mkwiro (Figure 1) forms part of the 25% rural community not connected to the national grid and therefore having the option of micro-grids to transform the fortunes of the communities who depends on candles, diesel generators, kerosene, and solar home systems to cleaner energy sources that are reliable and cost effective. The installation of Microgrids provides cleaner and cost-effective source of energy as an alternative to fossil fuel. The availability of cleaner and more cost-effective sources of electricity acts as a key factor towards enhancing the growth of people's life standards. The improvement of population life standards is enabled through the provision of central enablers such as health centers, schools, cold storage facilities and police stations. These services are currently not available, subjecting the whole population towards high mortality rate and low economic activities.

Mkwiro and Wasini island is a home of tourism and fishing as the leading economic drivers of the remote islands and are on the climate frontline with sea level rise as the major threats to the community in the islands. Therefore, energy reliable microgrids would transit the community from the heavy use of fossil fuel to zero fossil fuel. Mkwiro island has an installed solar power with capacity of 13 KW three phase PV system. The system powers a 500kg/day flake ice maker equipment thar produces flake ice for commercial and community -based organization members for domestic consumption. And supplying electricity to sea weeds dryer who members to community-based organization (CBO). Such solar PV system with storage is known as Microgrids or Minigrids(Kurauka, 2019).

Figure 1- 1 Mkwiro island (source: Renewable Ninja)

1.1.1 Microgrids

The entrenchment of renewable energy sources is growing very fast with Kenya for example being a hub and leading country in renewable energy sources (RES) power generation from hydro, wind, and solar generators with 85% of its energy generated in the whole of East Africa. This research focuses on energy supply and demand side optimization through a mix of solar and energy storage systems. Such a mix is known as Microgrids. Kenya is known to have constructed about 68 Microgrids in the country serving both urban and rural communities.

The current practice both in the country and the whole of sub-Saharan Africa, Microgrids have always been seen as a mix of renewable energy sources (RES), storage systems and a diesel generator. In this case Microgrids have drawn its definition as a group of interconnected loads and distributed generations that act as a single controllable electrical entity and can operate in both grid-connected and islanding modes (Ton and Smith, 2012). Microgrids have been tested and have shown that they are able to provide sufficient, resilient power and reliability for rural communities. Also, they have demonstrated as an alternative in making utility grids resilient in case of power blackouts and during manmade and environmental threats in many countries.

Microgrids have been used to minimize forecast error by smoothing energy generated from volatile feeds and ensure its components produces a defined load profile. Unlike utility grids, microgrids construction is fast and could be built in less time and cost. However as much these grids are used for creating resilience, they also face challenges that have seen many of them non-resilience as the case of flake ice maker 13Kw Microgrids not meeting its load demand is typical example that creates study to done on how resilient Microgrids are as much they are used as fallback system in utility grids as way of making them resilient which is the current practice.

1.1.2 Resilient Microgrids

Technological niches that have come due to rapid innovations in renewable energies technologies which has created pressures in the existing regimes creating fears of universal energy access for all (Walter ., 2019). This new emergence has shaped existing regimes that are likely to interfere with optimal operation of microgrids if not modelled to suit the dynamic community energy demand (Thomson, 2019). The generic definition of resilient micro grids refers to a grid whereby when the community or communities loads demand, and in particular critical loads that offer services to the intended community or communities, receive reliable, regular power supply and contingency measure in place in the event of power blackout (Kandaperumal & Srivastava, 2019).

Resilient microgrids can easily degrade to non-resilient due causation factors such as power outages, weather, natural disasters, accidents, and equipment failures (Kwasinski, Andrade, Castro-sitiriche, & O'neill-carrillo, 2019). Other issues such as human operational factors and dynamic loads need to be investigated during modelling. This concept of resilience enables the development of countermeasures that can control potential threats. J. Jasiunas et al (2021), resilient energy systems are known to be robust, reliable, risk, vulnerable, agile, stabile, survivable, flexible and fault tolerance systems able to deal with moderate disruptions at lesser cost and also deal with extreme and other nascent threats such as dynamic loads among the community (Jasiunas, Lund, & Mikkola, 2021).

Microgrids resilience differs with reliability in time dependency, severity, likelihood of threats addressed to. Resilience is built on the knowledge of strength together with flexibility. J. Jasiunas et al (2021) agrees that a resilient system without flexibility can break with ultimate catastrophic effects when operating outside the designed conditions (Jasiunas, Lund, & Mikkola, 2021). The subject of robustness has been associated with technical failures in energy systems under engineering and natural sciences disciplines. Resilient Microgrids are known to have characteristics with high redundancy, functional diversity, adaptability, and modularity (Jasiunas, Lund, & Mikkola, 2021). Where such a micro-grid would bend rather than break when faced with both known and unknown threats. And this can be achieved by using bottom-up modelling tools and ensuring optimization is done stochastically.

1.1.3 Optimization of Microgrids Components

Microgrids are designed in achieving desired goals, some of these goals depends on the designed components intended in meeting certain requirements, these requirements are achieved by ensuring a thorough dimensioning on critical properties is done (Masrur, Senjyu, Islam, Kouzani, & Mahmud, 2020). Microgrid resilience is affected by either under sizing or oversizing components, to avoid these scenarios the individual components in the Microgrid system must be optimal sized. Optimization is therefore the process of sizing system components to meet the desired outcome of the Microgrids.

Optimization can be done for both linear and non-linear problem constraints, but since the problem defined is non-linear with constraints which creates a trust-region. A trust-region optimization is used in mathematical optimization to resemble a subset of a feasible region of the objective function which is approximated using a model function which in most cases is a quadratic function. Optimization of energy supply led to energy resilient, reduces energy cost reduction and minimizes the run-time of the generators (GENSET), hence reducing carbon dioxide emissions. (Siemens, 2022)

In enhancing Microgrids resilience, several models are being developed to help in sizing and early determination of any threats that endangers the systems. The stochastic optimization models can determine multiple probabilistic load scenarios within a single optimization problem. It also the stochastic optimal sizing of the microgrids enhances resilience to shocks in the expected load compared to lowest-demand sizing, though with minimal cost and improved dispatch flexibility compared to high demand sizing. (Stevanato, Balderrama, Lombardi, Quoilin, & Colombo, 2019)

1.2 Problem statement

Countries are on rush to ensure every citizen have access to cleaner energy. These countries have promoted installations of standalone hybrid systems in remote areas to meet energy for all. These installations are done without proper due diligence of studying and optimizing to establish performance, reliability and sustainability of the hybrid power stations. The standalone hybrid power stations are installed with back-up diesel generators making them to have a low contribution of renewable energy. This is because the energy generated is entirely by diesel generators. Thus, this study aimed at covering this existing gap in relation to standalone hybrid microgrid in rural areas, assess their sustainability and feasibility to rural electrification access which includes optimization to improve reliability, availability, annualized system cost, net present cost, and least cost of energy.

1.3 Objectives

1.3.1 General objective

The aim of this study is to develop a Block Energy Microgrid model for the Island of Wasini and optimize it to improve on annualized system of cost, net present cost, least cost of energy, availability, and reliability.

1.3.2 Specific objectives

i. To identify energy supply challenges of renewable energy sources.
ii. To review existing techniques used to build optimal microgrids
iii. To develop a microgrid model for Wasini islands.
iv. To develop a suitable algorithm to optimize the model
v. To test the energy model annualized cost, availability, and reliability.

1.4 Research Questions

i. What are the renewable energy supply challenges on microgrids?
ii. How have the existing techniques been used in building an optimal energy supply for Microgrid?
iii. How can an optimal BlockEnergy Microgrid model be developed?
iv. Which is a suitable algorithm to optimize energy sources for BlockEnergy Microgrids for Wasini islands?
v. How reliable is the optimized BlockEnergy Microgrid model for Wasini islands?

1.5 Justification.

The Sustainable development goal (SDG) 7 and the climate action is igniting nations worldwide to connect every home with access to electricity whose generation resources are net zero fossil fuel that will enable with the goal of meeting the 1.5 degrees Celsius to save the earth from harsh weather by 2045. This niche has necessitated nations to decarbonize their grids system by adopting clean energy technologies such as wind, solar, hydro, and geothermal power sources. However, rural islands such as Wasini and Mkwiro village would need a Microgrid that is energy resilient, because the course way that separates it from mainland creates challenges of even having regular operational and maintenance visitation.

Sustainable microgrids will create better health care, leverage educational justice, and have proper control on post harvesting waste by ensuring there is sustainable and reliable electricity supply to school, mosque, dispensary, and the flake ice maker production unit. Energy reliable microgrids will create a 24/7 economy in the island and this will contribute to the growth of domestic product (GDP) growth of the country since it will reduce stress on the power distribution grid.

Sustainable standalone microgrids will create a niche of modernizing households in using modern cooking super-efficient appliances, domestic refrigerators, TV, and even boost the growth of tourism industry. This will help in reducing mortality rate by ensuring the cold chain supply for vaccines in the dispensary is adequately reliable supplied without the concern of losing vaccine potency. This will help reduce carbon emission and ensure maintenance to the required levels. The study intends to shape the microgrids designs using diesel generators as backup system to make the system cost effective and reliable. The study was to inform policy makers on best practices of energy policy formulation and implementation on installation of microgrids in rural areas. Moreover, the study will be of great importance to renewable energy researchers, technicians, and academia in building their knowledge for future theory and practical research work on BlockEnergy microgrids.

1.6 Scope and Limitations

This research, limited its study to energy modelling of annualized cost, least cost of energy, reliability, or availability challenges to microgrids by monitoring energy supply sources and human error operation. Any other energy availability challenges to microgrids will help in modelling and optimizing robust and reliable microgrids for the future. Energy availability and reliability falls into two categories, that is energy supply availability and reliability indices and load management availability and reliability indices. This, therefore used on the use of bottom-up stochastic optimization of energy supply reliable BlockEnergy microgrids for Wasini and Mkwiro islands and therefore availability and reliability indices were seen ideal in checking the overall performance of the individual energy source found in the case study area without affecting the outcome of the model.

Chapter 2 Literature Review

2.1 Introduction

This chapter reviews microgrids renewable energy supply challenges, renewable energy sources effects on microgrids performance, and microgrids design techniques. This chapter will also review existing supply and demand side optimization models and algorithms applied by other researchers in various jurisdictions. The chapter is divided into two sub-sections, that is theoretical and empirical frameworks as follows.

2.2 Theoretical Framework

The review will focus on supply and demand side challenges facing microgrids, and the existing supply side and demand side optimization techniques and algorithm that will be used to examine effects of technological niches in the context of rural communities transiting to energy efficient appliance such as electric pressure cookers.

2.2.1 Supply Side Challenges

Renewable energy sources through distributed energy resources, provide a way that will enable universal power access to islands and rural communities. However, BlockEnergy microgrids faces challenges in both supply side and demand side, that need a model that will consider during planning phase. According to D. Logan, C. Neil, and A. Taylor (1994) he stated that the supply side and demand side are faced with five challenges that are so critical in modelling RES microgrids. Table 2-1 provides a summary of the five renewable energy sources (RES) challenges given as capability, availability or reliability, location, modularity, and risk diversity(Logan et al., 1994). Solar and wind energy sources are known for intermittent making not a reliable source of power. The intermittency of Solar PV depends on the position of sun and clouds, while tidal energy depends on the low and high tides. Also, wind dependent on wind speed.

2.2.1.1 Capability and Availability

There are 3 RES sources found on the island, Tidal wave, wind and solar. Tidal wave energy has similar characteristics as the conventional sources in operation and effect on the microgrids. The capability and availability of wind and solar are subject to both predictable variations and intermittent, wind and solar are affected by both time-dependent and load modification.

The time dependent nature of these resources must be considered during modelling to capture the effects of dispatch on other system generation and production costs. Load modifiers are hourly load profiles that need to be specified to account for both predictable and random components. Load modifiers can be either short-term fluctuations or multiplicity, short-term fluctuation effects occur when the microgrid is largely made-up of RES as generators.

The multiplicity effect from load modifiers results in small powers sources to make microgrids, this effect improves generation reliability during blackouts of an independent power source. However, this effect cannot be applied to areas with weather related correlations on the output of RES in the same site. It is therefore important to consider multiplicity and short-term fluctuations in modelling reliability and capacity.

2.2.1.2 Modularity

Modularity is the characteristic of microgrids consisting of both small size and short lead times. This type of power system tracks the load growth and manages demand uncertainty, also reduces total system cost, the amount of over-capacity, the risk of using alternative option and the AFUDC costs.

2.2.1.3 Diversity

Diversification benefits narrow the bandwidth of uncertainty in a total system cost. A zero-fuel cost RES option with risk of related capital and non-fuel operating costs provides diversity in a microgrid whose benefits can be quantified by a portfolio analysis and energy reliability analysis. Therefore, diversity modeling is key in evaluating the relative cost stability of non-oil and non-gas resources.

2.2.1.4 Location

RES location affects the total costs, where the total cost is the marginal transmission and distribution costs. Location effect determines the additional costs for interconnecting the resource to the system, the impact of a resource on the total system losses and the distributed application of renewable energy and other resources can defer transmission and distribution reinforcement and thereby decrease overall transmission and distribution costs. Therefore, during modeling, location effect must be accounted for in the full cost-benefit analysis.

Challenges	**Renewable Energy Technologies**	**Demand Side Management**
Capability a) **Peak capability** b) **Energy capability** c) **Seasonal profiles** d) **Hourly profile**	Hydro, solar, and wind options typically Pronounced seasonal profiles. Solar and wind options also have pronounced hourly profiles.	Pronounced Seasonal and hourly profile.
Availability a) **Intermittence** b) **Forced outages** c) **Maintenance requirement** **Correlation with:** a) **Weather** b) **System demand** c) **Hydrological conditions**	Wind and solar are intermittent. Units in the same area are correlated with each other and may be correlated with weather-sensitive component of system demand.	Demand impacts with both the weather sensitives component of system demand and long-term demand growth.
Location a) **Delivery point: substation/feeder.**	Connected at transmission level. Can be targeted to defer transmission or distribution upgrades.	Connected at transmission for large industrial customer or distribution level for other customers. Can be targeted to defer transmission or distribution upgrade.
Modularity a) **Incremental size.** b) **Pre-construction lead time.** c) **Construction lead time.**	Incremental sizes and lead times of RES. Typically smaller and shorter than for conventional options.	Demand side management has no minimum incremental size, but the maximum size of DSM option is limited. DSM programs may be implemented with a lead time of only 1 year.

Table 2- 1 Summary of RES challenges

2.2.2 Optimization Techniques

In this theoretical review a deeper analysis of optimization techniques is either classified as conventional, non-conventional, hybrid or meta-heuristic. Table 2-2 shows a summary of the discussed five major optimization techniques on energy demand, unit commitment, demand management and forecasting. These techniques were reviewed to a certain simplicity, efficiency, reliability, adaptability, and capability which other researchers have applied.

2.2.2.1 Mixed-integer Linear Programming (MILP)

Mixed integer linear programming (MILP) is a conventional based energy management system which is highly used in energy management systems in microgrids because of its simplicity, and they have low computational requirements. MILP is a mathematical model that a problem and its requirements are modeled using linear relationships and evaluated through linear objective functions(Lin et al., 2012).

2.2.2.2 Genetic Algorithm (GA)

Genetic algorithm (GA) is an evolutionary algorithm that applies the principles of biological evolution such as reproduction, mutation recombination and selection. It is a highly used technique in modelling energy management systems to optimize the battery life loss cost, operational and maintenance cost, fuel cost and environmental cost. Nonlinear relationships are the problem, constraints, and objective functions. In the context of deterministic optimization, the problems modeled are very challenging(Lin et al., 2012).

2.2.2.3 Stochastic Optimization Algorithms (SP)

Stochastic optimization finds out proper solutions to multiple problems same as deterministic optimization(Collet & Rennard, n.d.). This method works for processes with random factors. Stochastic algorithms do not guarantee getting an optimal result for a given problem, however, it uses the principle of probability to find out the globally optimal solution which relates with the available computing time, and its probability of getting globally optimal result increase as the application time increases, therefore with an infinite time of application the globally optimal result would be 100% which is not possible with stochastic algorithms(Garcia, 2022).

Stochastic optimization reaches good a result, good enough with feasible sufficient time, hence a good algorithm for natural applications. The advantage of stochastic optimization is the possibility of controlling the execution time, that results for a complex problem with a large search space can be obtained in a short time. Hence an effective and accurate technique for optimizing energy scheduling.

2.2.2.4 Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a swarm intelligent based energy management system, that uses natural swarm systems that includes the collective behaviors of decentralized agents with the purpose of solving complex problems. PSO investigates behaviour such as ant colonies, bird flocking, animal herding, hawks hunting and fish schooling (Garcia, 2022). Researchers have applied PSO principle in addressing the multi-objective energy management algorithm to optimize the scheduling of BESS in solving power mismatch problem and used to diversify energy management problems. Particle swarm optimization techniques are flexible and rapid in responding to any intermittent occurring in systems to achieve a global objective of reducing the operational cost.

Optimization techniques	**Simplicity**	**Efficiency**	**Reliability**	**Adaptability**	**Forecasting**	**Energy demand**	**Unit commitment**	**Demand management**
MIP	Good	Bad	Moderate	Good	Moderate	Moderate	Bad	Moderate
SP	Bad	Bad	Bad	Bad	Bad	Bad	Bad	Bad
GA	Moderate	Moderate	Moderate	Moderate	Good	good	Moderate	Moderate
PSO	Good	Moderate	Moderate	Moderate	Very good	Good	Moderate	Moderate

Table 2- 2 Optimization techniques summary

2.3 Empirical Frameworks

This section reviews other cited works on basic models of microgrids components, which includes, Solar PV, wind, tidal, and energy storage systems. Since microgrids are built on available natural resources which include energy sources such as solar, wind, tidal currents, and storage systems to store excess energy produced. In the context of this study, modelling of BlockEnergy microgrids for Wasini islands will be composed of BlockCentral microgrids and BlockLoop nanogrids generation from household or critical loads rooftops and will consist of local available renewable energy sources (RES) and energy storage system (ESS). The renewable energy sources will include solar, wind, and tidal, while the energy storage system will include battery energy storage system (BESS) which could be either lithium ion or lead acid.

2.3.1 Modelling Solar Photovoltaic (PV) Power

Solar power is generated from sunlight, which consists of radiation that can be used as an energy source. The radiation from sunlight is trapped and converted to energy using solar panels, the panels act as transducers that convert solar radiation into electricity. The panels are made of several solar cells which consist of semiconductors with characteristics of photovoltaic effects which determines its efficiency at the maximum power point (MPP) on its PV power curve.

The photovoltaic models describing the PV power curve characteristics are more practical for assessing the PV systems, operation and the generation of maximum permissible power(Teyabeen & Jwaid, 2022). This study used empirical model to estimate the power output of the applied PV modules. Empirical models are mathematical model that requires global and meteorogical parameters as input.

2.3.2 Modelling Wind Power

Wind power is generated from the kinetic energy of air. A wind turbine acts as a transducer that converts air kinetic energy into electricity with the help of rotors and blades. This can be demonstrated in a wind power curve, which provides the relationship between wind power and speed. Power curves are the standard of the wind industry and they demonstrate the critical performance characteristics of a wind turbine which includes the rated power, cut-in speed, rated output speed and the cut-out speed(Yun & Hur, 2021).

In this study a probabilistic modelling approach was used to enhance power output of wind turbine. The power out of wind turbine is determined by the wind speed and the relationship between this two parameters are nonlinear with cut-in and rated speed (Yun & Hur, 2021).

2.3.3 Modelling Tidal power

Tidal power is currently considered as an alternative source of sustainable energy. Tidal power is generated from tidal current which has huge amounts of energy that can be converted into electricity. According to tideschart(2023), for wasini island, tides level could range from the highest level of 4 meters to the lowest level of 0.9 meters, meaning tides are predictable unlike wind and solar(*Get Wasini Island's Tide Times*, n.d.).

According to Oniyeburutan and Uhunmwangho (2021), in a study of mathematical modelling and simulation of tidal energy, they modelled tidal system by considering, tidal energy as the total energy of the sum of potential energy of water in the channel and kinetic energy due to the flow of tidal streams(Oniyeburutan & Uhunmwangho, 2021).

2.3.3 Models of Energy Storage Systems

Modelling energy storage systems is critical in microgrids that entirely rely on renewable energy sources, this energy sources are faced with variability challenges and therefore they can render a microgrid unreliable and incapable resulting in outages. Energy storage systems act as energy arbitrage during off-peak and high peak demands, and they can also be used to smoothening renewable energy generation, operating reserves for electricity regulations, load following to follow longer term(hourly) changes in electricity demand, to black-start after system wide failure (blackout). There are 4-energy storage technology in applications, that is mechanical, thermodynamic, electromagnetic, and electrochemical.

In the context of this study, a review on electrochemical storage technologies is considered as the focus of research in reducing storage size. The electrochemical storage technologies reviewed is on the battery energy storage systems that is, lead acid and lithium ion because of their low cost per KWh and commonly applied by majority researchers in microgrids and electric vehicle(Alemayehu, n.d.).

2.4 Models and Frameworks

The study reviews models and algorithms applied in previous studies, geared towards modeling, and controlling energy supply to achieve optimal solution in short time cycles. This section therefore reviews the shortfall of the mathematical models and algorithms formulated by other researchers in optimizing energy supply challenges to achieve reliable and available power supply in rural areas.

2.4.1 Energy Supply and Demand Side Optimization Models

In 2017, Peng Kou, deliang ling and Lin Gao proposed a stochastic energy management method that applied Chebyshev in equality and delta method to optimize a problem that turned into quadratic and linear programs. The proposed model failed to consider incremental analysis of the RES, economic analysis and the demand response programs(Kou et al., 2017).

In modeling hourly demand response in day-ahead scheduling to manage the variability of RES, Hongyu Wu, Mohammad shahidehpour and Ahmed al-abdulwahab (2013), proposed a stochastic optimization model which included the hourly demand response in managing variability of RES. This model however has not been tested on a system with BlockEnergy microgrids and energy economic analysis among prosumers are not considered(H. Wu et al., 2013).

In the study of decentralized renewable energy resources generation management and demand response in power distribution networks, bahrami Shahab, Amini m. hadi, shafie-khah Miadreza and catalao Joan P.S (2018), formulated a bi-level optimization framework to manage distribution network(Bahrami et al., 2018). During modeling the study investigated uncertainties that make RES unsuitable for standalone microgrids, however it failed to investigate the key roles played by energy storage systems and energy economic analysis among prosumers. This study also ignored the load flow constraint.

The study on convex relaxation investigated by Andrea’s Venzke, lejila halilbasic, Uros Markovic, Gabriella hug and Spyros chatzivasileiadis (2017), suggested an optimal power flow constraints that can provide guarantee for global optimality. The model was tested on IEEE 24 and 118 bus systems.

2.4.2 Energy Supply and Demand Side Optimal Algorithm

In 2016, Nima nikmehr and Sajad Najafi ravadanegh recommended an algorithm to evaluate a multi-microgrid reliability, the algorithm solved the problem using reliability maximization and stochastic techniques. In contrast the algorithm did not consider the amount for the economic analysis among the prosumers and the influence of demand response programs(Nikmehr & Najafi Ravadanegh, 2016). A game of theoretic model and its equilibrium analysis was proposed by Joohyung lee, Jun Guo, Jun kyun choi and Moshe Zukerman (2015), to model energy economic analysis of multi-microgrids through designing a hierarchical decision-making scheme. This algorithm ignored uncertainty and incremental analysis(Lee et al., 2015).

In 2017, Mehdi Jalali, Kazem Zare and Heresti Seyedi suggested a bi-level programming algorithm to run an operation scheduling of distribution network operator. The authors used a game theory technique to minimize the operation cost of the distribution network operator(Jalali et al., 2017). In this study the algorithm considered demand response, however, in contrast uncertainty of input data was not included and, the objective of game theory approaches was to determine the equilibrium point and not the optimal solution and therefore could not guarantee pareto optimal solution.

According to Stevanato (2019) study on stochastic approaches to modeling off-grid energy systems, coupled a stochastic load generation model with two-stage stochastic micro-grid sizing model to consider multiple probabilistic load scenarios within a single optimization problem(Stevanato et al., 2020). The advantages of the hybrid models in applications increases robustness to shocks in the expected load compared to a best-case (lowest-demand) sizing, though with a lower cost and better dispatch flexibility compared to a worst-case (highest-demand) sizing. It can also predict load and supply uncertainties in case of multiplicity.

In 2022, Atkins proposed a high-resolution bottom-up stochastic algorithm model for the generation of load demand profiles. According to Atkins (2022), the algorithm has the ability to assess reliability, availability, maintainability and productivity of complex system(Lombardi et al., 2019). This algorithm has the advantage of assessing a multivariable characteristic that might include high cost and complex systems that take long to analyze. In contrast, the algorithm ignored economic analysis for the individual renewable energy technology and includes diesel generator model.

The recommended algorithm, is flexible and can model many factors that may affect a system(Lombardi et al., 2019). The proposed algorithm proved to be effective in procurement contracts, what if studies, sensitivity analysis, equipment redundancy, equipment criticality, delayed failures, can export generated results for failure mode, effects, and criticality analysis (FMECA) and for cost-benefit analysis. However, ignores incremental analysis and includes diesel generator.

According to Stevanato (2020), he stated that, “the proposed MicroGridsPY algorithm model is a two-stage stochastic microgrid optimization that accounts for the possible demand scenario through an uncertain probability of occurrence.” The algorithm has considers a multi-year capacity expansion, evolving electrical loads, it performs multi-step investments, and it considers domestic hot water demand(Stevanato et al., 2020). In contrast MicroGridsPY model considers diesel generator as backup for RES microgrids in rural isolated areas(D. Wu et al., 2020).

In 2017, Farhad samadi gazijahani, Sajad Najafi ravadanegh and Javad Salehi, proposed a stochastic multi-objective model for energy management of networked microgrids, while applying scenario-based stochastic model and risk-based techniques. However, this study failed to account for demand side management(Gazijahani et al., 2018). According to, Hossein haddadian and Reza noroozian, (2017), they proposed a heuristic technique for operating a distribution system. In this study, the algorithm minimized costs and considered grid losses. In contrast, the algorithm failed to consider demand response(Haddadian & Noroozian, 2017).

The literature review conducted from other related works, it can be concluded that cooperative modeling determines an optimal solution in a problem, in contrast to a game theory, where the aim is to determine the equilibrium point and not an optimal solution. Therefore, the study applied a mathematical model and algorithm that can be used in a three-stage stochastic, multi-integer linear programming which guarantees an optimal solution.

2.5 Microgrid Architecture

Figure 2-1 is a hybrid microgrid architecture that distinguishes AC and DC loads grids interlinked with bi-directional AC-DC converters. The DC and AC bus caters for DC and AC loads respectively, with the distributed renewable energy sources and energy storage systems connected to the individual buses. This architecture installs critical loads on DC feeder, while robust loads are in AC feeder, therefore it is prone to energy wastages due decrease in conversion phases. The architecture also faces power balance challenges.

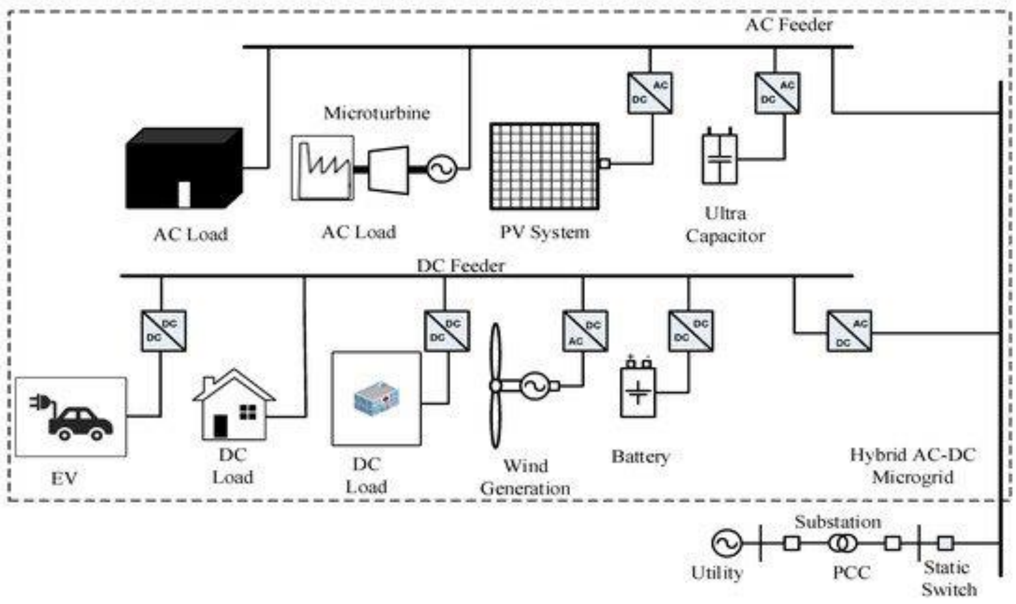


Figure 2- 1Microgrid architecture (Xu et al, 2021)

2.6 Gaps in Reviewed models and frameworks

Table 2-3 presents existing gaps of the reviewed models and frameworks for both energy supply and demand side optimization models. In these reviewed models and frameworks, the existing gaps or limitations was the inability to model and simulate incremental, economic, energy storage analysis and some treated all technologies linearly as summarized in table 2-3.

Model and frameworks reviews	**Focus**	**Limitations /gaps**
Distributed EMPC of multiple microgrids for coordinated stochastic energy management	Optimize problem into quadratic and linear programs	Proposed cannot model incremental analysis, economic analysis, and demand response
Hourly demand response in day-ahead scheduling for managing the variability of RES	A stochastic optimization model, schedule power system hourly	Not tested in BlockEnergy microgrid and energy exchanges among prosumers

A decentralized renewable generation management and demand response in power distribution networks.	A bi-level optimization framework, used in managing distributed networks, it considers uncertainties	Cannot investigate the role of energy storage systems, energy economics among prosumers, ignored load flow constraint.
Convex relaxations of chance constrained AC optimal power flow.	Provides guarantees for global optimality solution, tested on IEEE24 and 118 bus systems.	
Reliability evaluation of multi-microgrids considering optimal operation of small energy zones under load-generation uncertainties	Investigates reliability using maximization and stochastic	Could not account for energy economic analysis among consumers and influence of demand response.
Distributed energy trading in microgrids a game theoretic model and its equilibrium analysis	Game theory model, analyze economic analysis.	Ignored uncertainty and incremental analysis.
Strategic decision-making of distribution network operator with multi-microgrids considering demand response program.	A bi-level programming, generates operation scheduling of DSO, a game theory, minimize operation cost, and focused on equilibrium point.	Ignore uncertainty of input data and optimal solution
Two-stage stochastic sizing of a rural micro-grid based on stochastic load generation.	Apply a bottom-up stochastic load profile scenario generation (RAMP), a two stage microgrid stochastic optimization model (MicroGridspy), investigates uncertainty and variability.	Treats all technologies linearly, based on water pump in formulating the model.
Novel procedure to formulate load profiles for off-grid rural	Formulation of daily load profiles for off-grid consumers, apply LoadProGen software, based on bottom-up stochastic optimization model	Ignores forecast load profiles, effects of load profiles uncertainty on the sizing of off-grid systems and optimum stochastic sizing regarding load profiles.

Table 2- 3 Existing gap in reviewed models

2.7 Conceptual Design

The conceptual architecture of Figure 2-1 provides a detailed architecture of building an optimal energy supply microgrid. The load profile scenarios generated in stochastic load profile algorithm is used as input to the 3-stage stochastic optimizer a multi-integer linear programming (MILP) for figure 2-2 below, a conceptualize optimization model design flow. The algorithm is based on the ability of the algorithm to optimize uncertainties, availability and maintainability in both demand and supply side as shown in the gap analysis summary table 2.3. The load classification from the field is done at data storage, then fed into a stochastic load profile modeler to generate load profile scenario for individual households. The load profile scenario generated by stochastic load profile generator, the effects on the site specific photovoltaic geographical solar energy production (PVGIS) data, wind and tidal energy is investigated to obtain optimal sized off-grid systems. The site-specific data, together with load profiles scenarios modeled in a three-stage stochastic optimization, a mathematical algorithm used to optimize energy supply of any microgrid system. The mathematical algorithm was used to generate optimal results that can meet critical loads and non-critical loads based on the MTF.

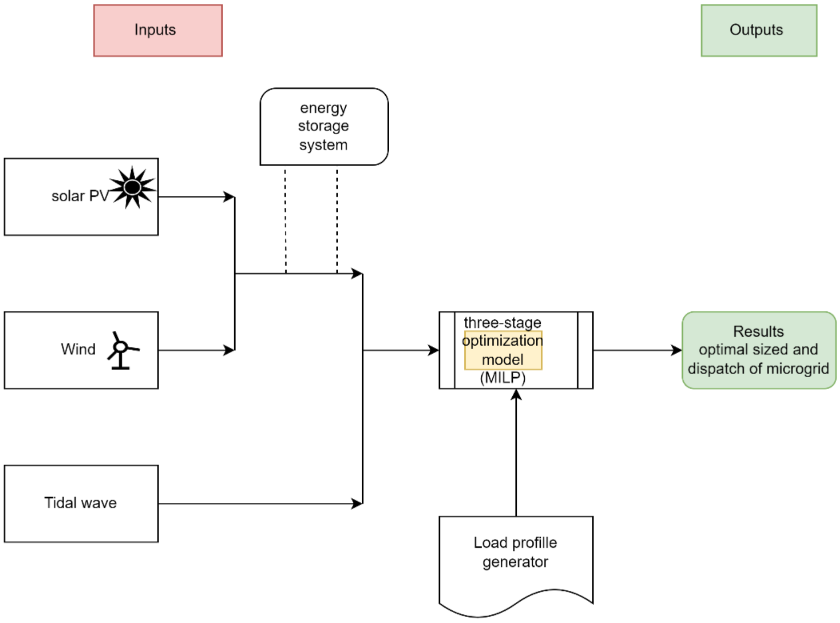


Figure 2- 2 Conceptual flow model (Author design)

2.8 Summary

The literature review conducted to validate this study, from other related works, it was concluded that cooperative modeling determines an optimal solution in a problem, in contrast to a game theory, where the aim is to determine the equilibrium point and not an optimal solution. Therefore, the study designed a mathematical model and algorithm that was applied in a two-stage stochastic, multi-integer linear programming which guaranteed an optimal solution that predicted uncertainty on load profile generated by prosumers using the model.

In Table 2-3, several gaps are drawn from the models and frameworks reviewed, however, the review on two-stage stochastic sizing of a rural micro-grid based on stochastic load generation and novel procedure to formulate load profiles for off-grid rural, points out the existing gaps that most researchers' ignored during modeling, some of the gaps ignored are effects of load profiles from prosumers, in ability to analyze incremental, economics, storage systems, demand response, and treating all energy technology linearly . These gaps formed the strength and basis of designing the model and its algorithm in this study. The study modeled a bottom-up two-stage stochastic model that was investigating the effects of load profile scenarios from prosumers on an optimum stochastic sizing for off-grids systems.

Chapter 3: Research Design and Methodology

3.1 Introduction

This chapter presents the research design and philosophy used in carrying out the study. It also describes the geographical characteristic of the study area, the methods of data collection together with data analysis technique applied during the study for both load demand and natural resources such as solar, wind and tidal wave energy. In addition, the techniques of modelling and designing algorithm is presented for both load demand and energy supply modelling are explored. Also, simulations software that can be used for modelling energy systems are presented and the reason is provided on the choice made by the author of using a particular MATLAB2016a. The technique for testing and analyzing while maintaining research quality together with ethical considerations are also discussed in this chapter.

3.2 Research Design and Philosophy

Research design is a technique used to solve problems, while research philosophy outlines the ways of solving problems. The research design technique in this study is experimental research. Experimentation is a process that involves manipulation of independent variables to determine effects on dependent variables. The experiment research philosophy will involve seven activities as follows, selecting relevant variables, specify the level of treatment, control the experimental design, choose the experimental design, select, and assign the subject, pilot-test, revise, analyze the data and finally test.

In this study, the author applied mathematical modeling using MATLAB 2016a as platform for initializing the input and output multicriteria factors and simulate the factors by drawing penalty function on any solution that falls out of feasible region. The optimal solution was simulated using particle swarm optimization technique. Particle swarm optimization(PSO) is an evolutionary algorithm that uses birds in determining the non-dominated solution. In this thesis, it was used to find the optimal annualized system cost, and energy reliability index.

In chapter 2, the literature reviewed provided a few optimization techniques and models such as mixed integer linear programming, genetic algorithm, and stochastic optimization algorithm. Genetic and particle swarm optimization(PSO) algorithm are both evolutionary, however, particle swarm optimization algorithm technique demonstrated flexibility and rapid in responding to intermittent sources of energy than genetic algorithm.

In this study, load demand was treated as the independent variable while renewable energy sources characteristics or challenges are the dependent variables that were manipulated against each other to obtain cost effective, reliable, and available microgrid. In varying the stochastic characteristics of independent and dependent variables of the microgrid a bottom-up stochastic load profile model was used, the independent variable load demand was varied to generate multiple probabilistic scenarios to enhance adaptability and sustainable variable cost.

The dependent variables of renewable energy sources (RES) that is variability and uncertainty, were manipulated using a two-stage multi-objective stochastic optimization model proposed to investigate the effects on independent variable load demand profiles for the island. This technique solved the optimization problem by embodying uncertainty that was likely to occur and provide an optimal stochastic BlockEnergy microgrids with flexibility to sustain multiple load scenarios.

3.3 Description of the Case Study

The case study adopted for the new experimental method independent and dependent variables of energy supply optimization microgrids, is the island of Wasini in Kwale county. Based on the REREC (2022) environmental impact assessment outcome conducted in the island the households are approximately to 400(Kurauka, 2019).

The island is off-the-grid that is, not supplied with utility grid and therefore forms part of the 61% of rural areas without access to electricity, however the county government of Kwale in collaboration with the Rural electrification and renewable energy corporation has staged to light the island using solar, energy storage system and diesel generator microgrid(Kurauka, 2019).

3.4 Data Collection

Statistical data is any material a researcher uses and analyzes to obtain a problem solution. Statistical data can be classified as primary and secondary data, primary data is the data collected in a study by the researcher, in contrast, secondary data, refers to the use of data collected in another study. This study used household load demand, solar insolation, wind speed and wave tidal height level as primary data. This data was collected using experimentation and questionnaire mode of data collection, a technique highly implored in primary data.

The experimentation mode of data collection involved selecting the independent and dependent variables which are under the control of the research, and this included the load demand as the independent variable and the renewable energy sources (RES) as the dependent variable. Whereas questionnaire mode of data collection is a technique of data collection through use of question seeking response from the people affected by the problem, the questionnaire technique was used in this study to collect arrange of information on socio-economic characteristics, attitudes, opinions that was used in forecasting energy generation and consumption in the case study area.

In this study, the researcher applied probability sampling technique that allowed every household of the population sample frame of Wasini island respond to questions as raised. The targeted population sample frame had a population size of 400 households(Kurauka, 2019), the study used stratified techniques, where the households were divided into socio-economic sub-sample. According to Mc combes (2023), suggested that the allowable margin of error in experimentation research falls between 4% to 8% when the confidence level is at 95%. Where he noted that, the margin of error is affected by sample size and population size (combes, n.d.). Therefore, for the purpose of this study an 8% margin of error and 95% confidence level was used that gave a sample size of 110 households that was used in generating load profiles that helped in determining energy demand and peak demand.

3.4.1 Load Demand Profile Data

The study used load demand profile data in modelling and simulation. Load demand profile data is a primary dataset that was used as an input data in the independent variable to generate load profile scenarios for each household energy consumption. In building cost effective, reliable, affordable, and sustainable microgrid for the case study area, a questionnaire method of data collection was used for this study, where the data was used to formulate load profile scenarios for every household, and which was used in validating the obtained optimal stochastic model and the generated algorithm.

In this study the questionnaire method was used to collect the following microscopic data in table 3-1. Table 3-1 demonstrate the input data used in designing the model. The model classified the data into user's classes, number of users for each class, electrical appliances or devices for each household, and usage habits which includes each appliance functioning time, window and functioning random parameters. In table 3-1 below shows microscopic data, defining its use in generating load profile that is critical in the development of the BlockEnergy microgrid model of the case study area.

1.	i	Type of electrical appliances such as light, mobile charger, radio, and TV
2.	j	Specific user class such as household, school, stand shop, dispensary, flake ice maker
3.	N_J	Number of users within the class j
4.	n_{iJ}	Number of appliances i within class j
5.	p_{iJ}	Nominal power rate (W) of appliance i within class j
6.	h_{iJ}	Overall time each appliance i within class j is on during a day(min): functioning time
7.	$W_{F.iJ}$	Periods during the day when each appliance i within class j can be on, that is functioning windows.
8.	d_{iJ}	Functioning cycle in minutes, that is minimum continuous functioning time once appliance ij is on.
9.	Rh_{iJ}	Percentage random variation of functioning time appliances ij
10.	RW_{iJ}	Percentage random variation of functioning window appliances ij

Table 3- 1 Input data required by the model

3.4.2 Renewable Energy Sources Data

The unpredictable nature of renewable energy sources factors was taken as input data to the model. This data was treated as a primary dataset, the dataset was used as input dependent data variables to the model. This dataset was used to investigate renewable energy resource data availability or uncertainty and their effects on energy planning capacity. Experimental techniques were applied to collect data which included inputs such as rated output range, capacity range, efficiency, construction cost, maintenance cost and operational constraints.

In this study the experimental renewable energy sources(RES) data was obtained from online databases and models such as weather station, Geomodel solar, IRENA, NASA, SANED, renewable ninja, PGVIS, and graham and hollards model (1990), Oliva model (2008) and huld etal (2012) respectively. The data was used in determining the model capacity planning of the available energy resources in the case study area.

3.4.3 Data Analysis

The primary data collected in this research method was analyzed using a stochastic bottom-up model. A stochastic bottom-up model is a quantitative data analyzer, that computes energy consumption for households or group of households and find the summation of the household demand. The household data analyzed above was applied as an input to build up the designed mathematical stochastic model that optimized energy supply for the case study area.

The aim of this study was to address the optimum stochastic sizing of supply side in relation to load profile and analyze the effects of load profiles uncertainty on the sizing off-grid systems. The aim of the study was not to forecast load profiles, but to formulate load profile that was used in investigating there effects on an optimized renewable energy sources microgrids. The appliances functioning time and functioning windows are critical to determining daily electric energy consumption and the coincidence behaviour of the appliances.

3.5 BlockEnergy Microgrid Model and Algorithm Development

The developed model and algorithm had aimed at optimizing and analyzing effects of household load profiles on RES supply respectively. The designed BlockEnergy microgrid for the study area overcame the challenges of annualized cost, least cost of energy, reliability, and availability. The developed microgrid consisted of BlockCentral, BlockLoop and BlockHome, where the BlockCentral consisted of battery management system and tidal wave energy, block loop is built with households which becomes prosumer and are coupled together as a ring with storage system, and finally the BlockHome is a household who is a prosumer and receives shared energy from BlockLoop and BlockCentral.

In building the BlockEnergy model and algorithm, the analysis of load profiles as input data is critical to this study. Therefore, sizing BlockCentral depends on the load profiles scenarios for both BlockLoop and BlockHome and according to A. Grandjean, J. Binet and G. Binet (2012), made the following conclusion for an ideal algorithm or model, "It must be parametric to simulate various scenarios, it must be technically explicit, i.e., the different specificities of the simulated appliances must impact the load profile results, it must be evolutive, i.e., new elements can be introduced to be simulated, it must be aggregative so that results can be obtained at different levels (household, city, region, etc.) and finally all end-user was considered in the load profile calculations"(Grandjean et al., 2012).

Therefore, putting into perspective of Grandjean et al(2012), this study designed a model that applies the above conclusion, to include the following five (5) characteristics of the case study area.

1. It must be based on input data that can be easily assumed based on practical experience on similar context conditions or by means of local surveys.
2. It must be based on a rigorous mathematical formulation which allows generating the load profile, i.e., apart from input data, the designer judgments should not affect the profile shape.
3. It must be bottom-up, i.e., the load profile formulation must rely on microscopic input data referring to each appliance's features within a specific type of user class.
4. It must build up the coincidence behavior of the appliances and the power peak value with regards to the existing empirical correlation between number of users, load factor and coincidence factor.
5. It must be stochastic to embrace uncertainty, i.e., given the input data, the procedure output should allow formulating a specified of realistic profiles within the given input data

3.5.1 Loads Profile Scenario Modelling

The purpose of this study was to analyze the effects of load profile during optimization of energy supply sources. In consideration of the types of appliances, the user classes, the number of users, the number of appliances, the appliances rate powers and the functioning times, the daily electric energy consumption (E_C) was determined using a bottom-up Stochastic Load Profile modeler, which quantifies the energy needs for various tiers of the multi-tier framework (MTF). The bottom-up stochastic load profile modeler incorporates coincidence factor as design input to generate stochastic loads profiles, and it can underline the impact of different load profiles on standalone PV systems. The bottom-up stochastic load profile model formulates the algorithm by stating the objective function and constraints.

3.5.2 Energy Supply Modelling

The optimization of BlockEnergy Microgrid deals with the fact that load profile scenarios affect cost, reliability, and availability of the energy supply system. This effect results in overestimation or underestimation and unreliable microgrid. It is true to say that the demand of rural villages will change based on unexpected events or develop as planned. The designed two-stage stochastic optimization algorithm can consider multiple loads scenarios at once and find a robust optimal solution.

The design optimization problem was formulated as a two-stage stochastic integer programming ng(SIP) with integer recourse, where the first stage (system design) involved selection and sizing of the installed units, selection, and capacity of the power connections between the sites, and finally the second stage involved reliability and availability of the microgrid on real-time operation. In this second stage the load of all the units, the on/off scheduling of the flexible units and the operational strategy of the storage systems was decided (recourse actions to the uncertainty).

The designed model stated with the formulation of problem objective function and constraints. The two-stage stochastic integer programming was modified to meet the main problem objective function of the study. The modification of the model excluded carbon emissions and load reliability indices as a multicriteria factor in modeling. During modeling, the first stage variables represented the investment (INV)decisions for each technology within the microgrid, while the second stage variables represented the operation cost of the microgrid during the 25 years lifetime of the project. And finally, the third stage variables are the load profile scenarios of the microgrid on the case study area.

3.7 Simulation Software

Modeling is the art of creating a virtual representation of a real-world system which includes software and hardware. While simulation is a process of evaluating a new design, diagnose problems with an existing design and test a system under conditions that are hard to reproduce in an actual system. The existing modeling and simulation software are MATLAB, CPLEX,GUROBI and XPRESS.

Modeling and simulation software such as HOMER, was not selected for application due to its black-box nature. This modeling software is black box because it does not let the user know or manipulate the input data, but it rather generates results. The case of HOMER allows only a single objective function for minimizing the Net Present Cost (NPC) as such the multi-objective problems cannot be formulated. After optimization process HOMER makes a chart for the optimized system configurations based on NPC and does not rank the hybrid systems as per levelized cost of energy. Also, HOMER does not consider depth of discharge (DOD) of battery bank which plays an important role in the optimization of hybrid system, as both life and size of battery bank decreases with the increase in DOD. Therefore, the DOD should either be optimized or be included in sensitivity inputs of HOMER. The other limitation with HOMER is that does not consider intra-hour variability and fails to consider variations in bus voltage.

RETSCREEN was not selected for modeling and simulation because it does not consider the effect of temperature for PV performance analysis. While HYBRID2, due to its limited access to parameters and lack of flexibility, was disqualified in modeling and simulating the designed model.

The choice of modeling and simulation software was based on software capabilities and problem domain. Rimmi Anand, Divya Aggarwal and Vijay Kumar (2017) stated that, " there is no single best solver for all types of problems or for all quality measures.(Anand et al., 2017)" however a best optimization software considers the nature of problem and computation time. Based on these factors MATLAB software performs better than CPLEX,GUROBI and XPRESS software on real life problems and computational time.

The energy supply model was developed and simulated on MATLAB 2016a version using intel corei5 vPro 7th Gen Hp laptop. The MATLAB 2016a served as the platform for initializing model multicriteria factors of load demand, weather data on intermittent sources of energy that is wind speed and solar insolation and , tidal wave energy data(tidal height), the technical and economic factors that satisfies problem objective function or problem constraints.

To obtain the optimal results, simulation was done using an evolutionary algorithm, that is particle swarm optimization(PSO). In chapter 2, table 2-2 shows optimization techniques summary, and based on this, particle swarm optimization(PSO) was selected due to its strength on simplicity, efficiency, reliability, adaptability, forecasting, energy demand and unit commitment against other algorithm.

3.7 Testing of Results

The purpose of this study was to address the optimum stochastic sizing in relation to load profiles and investigate the effects of load profiles uncertainty on a sized off-grid systems. In achieving this aim the model used input data surveyed or assumed in rural areas, the model is a stochastic bottom-up approach with correlations between load profile parameters to build up the coincidence behaviour of electrical appliances on energy served from the intermittent sources.

The developed model formulated the load profile for schools, hospitals, shops and compared the outcome profile with island metered data. The model was tested on cost effectiveness, robustness, reliability, and availability. The tested results were compared with those of anti-bee colony (ABC) for similarity and standard deviation or convergence level.

3.8 Research Quality

This seeks to uphold exacting standards of research by ensuring that all materials used to develop the idea, design and its implementation was obtained from reliable sites with reputable decades of topical search which formed the primary research source of this thesis. In ensuring reliability of the microgrid, the case study area data was used to assess and train the model. The two-stage stochastic method used site-specific data to re-process and analyze the collected data while considering the problem objective function.

3.9 Ethical Considerations

BlockEnergy microgrid with a blockchain was built from initial principles of modeling and simulation. The modeling and optimization technique represents an original idea of the author, since most microgrids design have a monotony architecture of either diesel or biomass generators as back-up to the microgrid. This phenomenon was demonstrated in the literature reviews conducted from both theoretical and empirical studies in this field. This study seeks to maintain the safety, security, and privacy of all its respondents in which they provided data, and hence there will be no footprint left to trace.

Chapter 4: System Model and Problem Formulation

4.1 Introduction

This chapter presents data collected from the case study outlined in chapter 3. The data collected through a field visit survey from 110 households classified based on multitier framework from tier 1 to tier 5 to give the average load and peak demand of the selected case study. In this chapter system modelling and objective function with its constraints both inequality and equality are developed and determined. Also, the simulation tool was selected to analyze data and generate the optimal configuration.

4.2 System Modelling and Objective Function

The model uses the bottom-up stochastic modelling on system components. The components which were used in modeling consisted of solar photovoltaic panels, wind turbines, wave energy converters, batteries, and inverters. A mathematical bottom-up stochastic equation was adopted to determine the optimal number of solar panels, wind turbines, batteries, maximum power output of wave energy converters, and maximum power rating for inverters. The number of these components were critical in problem formulation.

4.2.1 Case Study Area

The problem formulation was derived from the methods outlined in chapter 3. In designing an optimal Block Energy microgrid shown in figure 3-2 conceptual flow model, the peak load demand of the case study area Wasini island was used. The case study area is situated at latitude -4.6425141958677 and longitude 39.356224244734825, the microgrid is to serve households with uncertainty load profile.

This study area has good availability of solar and wind resources throughout the year, the site-specific weather data was collected from Renewables ninja Solar photovoltaic power (PV), PGVIS and global wind atlas. Renewable ninja solar photovoltaic power, PGVIS and global wind atlas were selected because they are open source and provide real time data compared to ARENA. The average wind speed and power density in this site is given as 6.484986187 m/s and 211 w/m^2 respectively at height of 100m, while the average solar radiation is 29.78283333$KWh/m^2/day$. Table 4-1 details load demand for 110 households. Wasini island has an average wave energy of 12.5KW/m, wave energy theoretical potential of 59TWh/year with wave energy applicability potential of 3TWh/year and a wave energy index of 38%. Table 4-2 is an economical and technical parameter associated with components or device used in the design for the study area. The lifetime of the project, the interest rate and inflation rate for the project is taken to be 20 years, 12.47% and 6.73% respectively.

4.2.2 Simulation Data

The primary data collected that was used for simulation came from global wind atlas, and renewable ninja solar photovoltaic an open source. This database was used to generate wind speed, tidal wave energy, and solar radiation for the case study area. Also, the peak load demand data for the area was collected using a questionnaire which was administered to 110 households.

4.2.2.1 Household Load Demand

The data collected from the survey shows that the majority of the 110 households own electrical appliances that use single solar panels to power them as depicted in table below. Using the multi-tire framework (MTF) tier 5, the data collected from the case study area, was used to measure the level of electricity penetration to characterize the usage rate based on the bottom-up micro-economic characteristics for this study.

The data collected from the 110 households, shops, flake ice makers, 2 dispensaries and two schools are summarized in Table 4-1. In this table, the case study area shows a load demand of 330.215KW/day which is extremely higher than the design target set for MTF tier 5 being 8KW/day. The power consumption was estimated to be 4610.47 KWh/day.

S/N	Appliances	Quantity	power rating (KW)	Hours per day	Consumption (KWh/day)

1	CFL	4	0.002	8	0.064
2	LED lamp	10	0.012	12	1.44
3	Ceiling fan	4	0.04	18	2.88
4	Hand mixer	1	0.2	0.5	0.1
5	Refrigerator	1	0.3	6	1.8
6	Television, video recorder	1	0.04	2	0.08
7	Computer	1	0.07	8	0.56
8	Electric cooker	1	0.3	0.5	0.15
9	Table fan	1	0.015	1	0.015
10	Electric iron	1	1.1	0.3	0.33
11	Smart phone/tablets/2Gphone	4	0.002	4	0.032
12	radio	1	0.004	4	0.016
13	food processing	1	0.2	0.5	0.1
14	washing machine	1	0.5	1	0.5
15	air conditioner	2	1.5	3	9
16	water pump	1	0.5	0.2	0.1
17	hair dryer	1	1.2	0.1	0.12
18	water heating	1	8.5	1	8.5
Total demand for one house					**25.787**
Number of houses				**110**	**2836.57**
S/N	**Deferable Loads**				
1	Community shops	2	33.33	6	399.96
2	Community fish storage depot	1	41.67	6	250.02
3	Flake ice maker	1	4	1	4
4	Hotels	1	10	12	120
5	Women group seaweed drier	1	100	1	100
6	Dispensary	2	20.83	12	499.92
7	Schools	2	25	8	400
Deferable load demand			**234.83**		**1773.9**
Total demand(household demand + deferable load demand)					**4610.47**

Table 4- 1 Case study area load demand

Figure 4-1 and figure 4-2 show a load curve and load duration curve respectively. Figure 4-1 is a load curve generated using the general model power equation $f(x) = a * x^b$, Where a and b are Coefficients (with 95% confidence bounds), the coefficients generated are a = 0.8692 (-0.182, 1.92) and b = -0.2098 (-1.053, 0.6338). The plots show a goodness fit of the following parameters sum of square error (SSE): 64.53; root-square: 0.02608; Adjusted root-square: -0.03479 and finally with root mean square (RMSE) of 2.008.

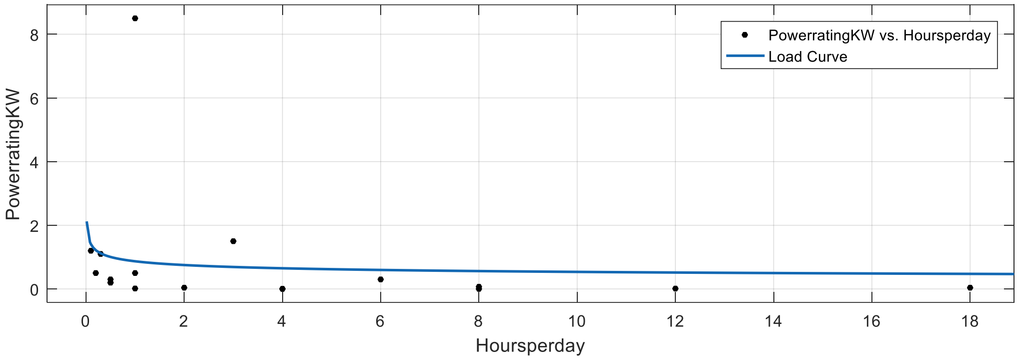


Figure 4- 1 Load curve

Figure 4-2 load duration curve was generated using linear model Polynomial equation. Figure 4-2 plays an important role in analyzing generating power economically and helped in selecting base load power plant and peak load power plants. $f(x) = p1*x + p2$ where x is normalized by mean 4.644 and std 4.864 and coefficients (with 95% confidence bounds) as p1 =18.9 (14.05, 23.76), and p2 =9.973 (5.217, 14.73). The goodness of fit generated a sum of square error (SSE) of 3039 , root -square of 0.7383, adjusted route-square of 0.7269 and a root mean square (RMSE) of 11.49.

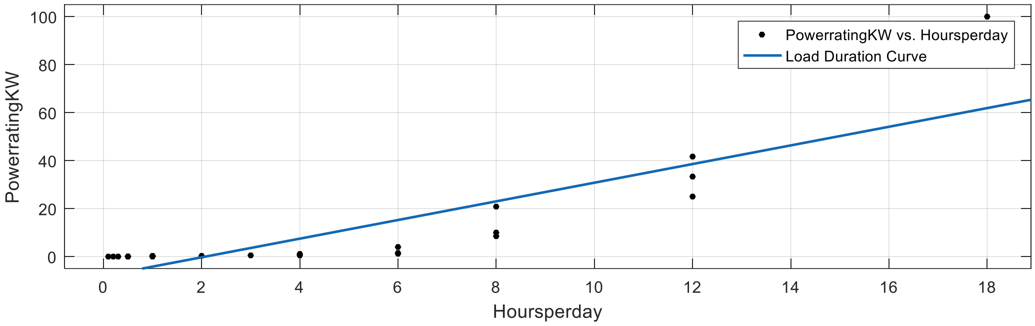
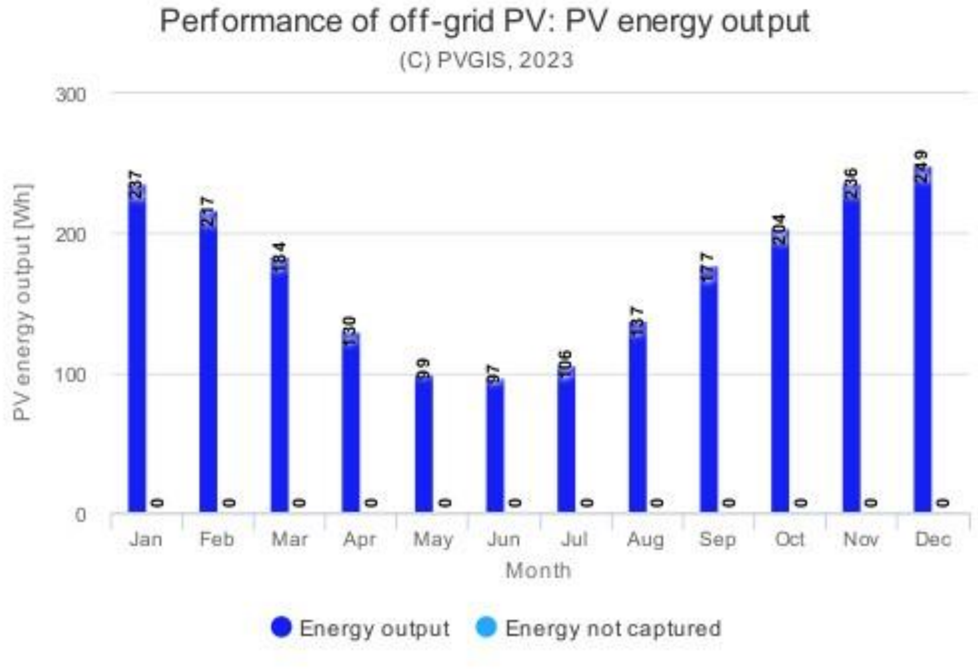


Figure 4- 2 Load duration curve

4.2.2.2 PV Electricity and Solar Radiation

The bar graph 4-1 is the site information obtained from the global solar atlas for the purpose of this study. The author chose PV system configuration of Ground-mounted large scale, Azimuth of PV panels with Default (0º), Tilt of PV panels with Default (5º) and Installed capacity of 1000 kWp. The site has an annual average of total photovoltaic power output and Global tilted irradiation of 1.685 GWh per year and 2105.4 KWh/square meter. The average monthly total photovoltaic power out is shown in the bar graph below, where May/June records the lowest solar radiation which is attributed to long rains together with cloudy sky.



Bar graph 4 - 1 Wasini island monthly solar irradiation, source: PVGIS

The PV power curves were used to aid in modelling of solar power. Equation 4.1 is a mathematical modeling expression that was used to model the generation capacity of solar in the case study area.

$$P_{PV} = SR \times \cos \emptyset \times \aleph_{\mu} \qquad \textbf{(4.1)}$$

where,

$\mathrm{SR} =$ solar radiation

$\emptyset =$ angle of incidence calculated and $\beta = 45°$

$\aleph =$ Efficiency of the maximum power point tracking (MPPT)

$A_p = area\ of\ the\ pv\ panel\ m^2$

$\aleph_p = efficiency\ of\ the\ PV\ panel$

4.2.2.3 Wind Power and Wind Speed

The wind power generated from wind speed is directly proportional to air density, rotor area, and the cube of the wind speed. In modelling wind power other researchers have used this relationship to determine the wind resource capacity. In this study equation 4.2 was adopted to calculate the amount of energy and number of wind turbine which was critical in obtaining optimal results for annualized system cost and reliability.

$$P_{Wind} = \frac{1}{2}\rho \times A_w \times C_p(\Lambda_w, \theta) \times v^3, \qquad \textbf{(4.2)}$$

Where,

$\rho = air\ density\ (\frac{kg}{m^3})$

$C_p = performance\ or\ power\ coefficient$

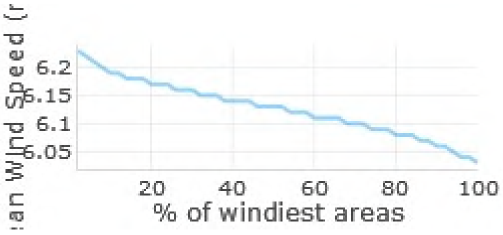
Λ_w
$= ratio\ between\ blade\ tip\ speed v_t \left(\frac{m}{s}\right) and\ wind\ speed\ at\ hub\ height\ upstream\ the\ rotor\ v_w(\frac{m}{s})$

$\theta = angle\ of\ the\ blade\ chord\ to\ the\ plane\ of\ rotation\ (or\ pitch\ angle)$

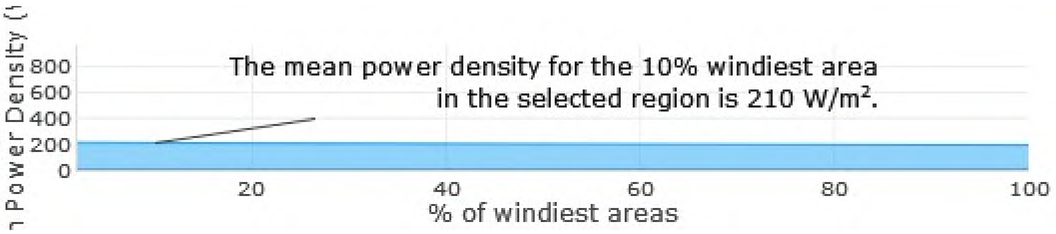
$A_w = area\ covered\ by\ rotor\ of\ wind\ turbine\ (m^2)$

Power coefficient is stated as the function of tip speed ration and pitch angle. Wind turbine’s ability to convert wind speed into wind power is characterized by its power coefficient. according to Betz’s equation limit, states that the maximum achievable value of power coefficient is $\frac{16}{27}\ equivalent\ to\ 59.3\%(\mathrm{Alemayehu, n.d.})$.

The bar graph 4-2 and 4-3 is the data for 10% windiest areas at a height of 100m with maximum wind speed of 6.19m/s and 210 W/square meter average power density on the case study area as generated by global wind atlas an open source.



Bar graph 4 - 2 wind speed m/s, source: global wind atlas



Bar graph 4 - 3 mean power density source: global wind atlas

4.2.2.4 Battery Energy Storage System(BESS)

In this thesis, storage of the intermittent energy sources generated was considered. The study considered storing surplus energy for future use in case of uncertainties such as low wind speeds and shading or other calamities. Equation 4-3 was adopted in modelling the battery energy storage system for the microgrid. This mathematical expression is a stochastic mathematical model which was used to determine the battery power in, battery state of charge (SOC), and the number of batteries required in the microgrid that can store the excess energy generated in equation 4-1 through 4-5.

$$b(t+\Delta t)=\begin{cases} b(t)+\Delta t\times p^{c}(t) & charging \\ b(t)-\Delta t\times p^{d}(t) & discharging \end{cases} \qquad \textbf{(4.3)}$$

Where,

b(t)=state of BESS at time t,

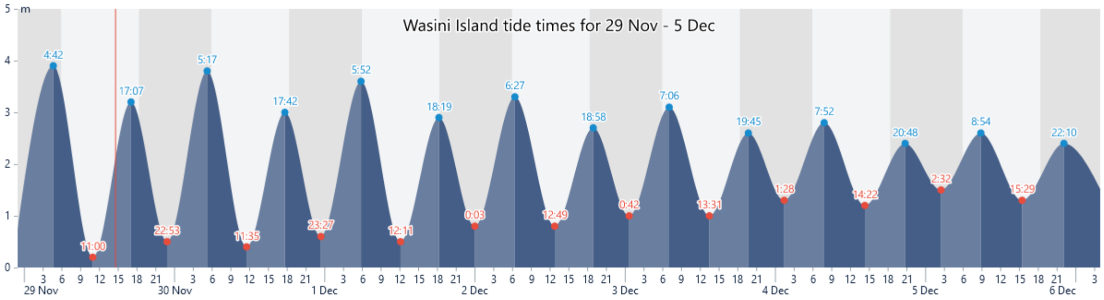
$\Delta t = time\ step$

$p^{c}(t) = charging\ rates\ at\ time\ step\ t$

$p^d(t) = discharging\ rates\ at\ time\ step\ t$

4.2.2.5 Wave Energy and Wave Speed

The bar graph 4-4 presents data collected from global wave energy map as of 29 November 2023 highlighting the wave peak/height at 4.42m and lowest being 0.2m, the average wave energy is 12.5KW/m, where the theoretical potential and applicable potential being 59 and 3 TWh/y respectively. The region would consume 7.86TWh of total electricity generated.



Bar graph 4 - 4 wasini island wave tides source: tides chart

In this study the tidal wave energy was converted to useful energy using a wave energy converter (WEC). Using the data from bar graph 4-4 , the tidal power equation 4.4 and 4.5 was applied to convert the tidal currents to determine the maximum power achievable based on the selected wave energy converter technical parameters provided in table 4-3.

Power from tidal currents

$$P_a = \frac{1}{2}\rho A V^3 \tag{4.4}$$

Where,

$\rho = seawater\ density\ (1025kg/m^3$

$A = Rotor\ blade\ area\ m^2$

$v = water\ current\ speed\ or\ velocity\ (\frac{m}{s})$

However, a turbine or marine turbine are noted in having mechanical losses due to friction, these losses can result in decrease power output hence affecting the efficiency of tidal turbines. Therefore, the actual power equation used in modelling changes to

$$P_{act} = 0.5\rho C_p A V^3 \tag{4.5}$$

Where,

$C_p = power\ coefficient$

Power coefficient is defined as the percentage of power generated considering all losses due turbine and Betz's law or power converter mechanical losses and heat losses. The power coefficient for marine turbines is given as a range from 0.35 to 0.5 higher than the power coefficient for wind turbine which stands at a range of 0.25 to 0.3.

4.2.3 Components Technical and Economic Data

This table is a summary of data collected from reference materials shown in the table. The table provides the technical specification of the devices in the microgrid, CAPEX and OPEX of the components.

Technical and economic data of the components used in the proposed energy supply models (ESM)				
Components	Parameter	Value	Unit	
Wind turbine	Rated power	250	KW	Baek et al. (2016)
	Cut in speed (Vcin)	3	m/S	
	Cut out speed (Vco)	20	m/S	
	Rated wind speed (Vrat)	11	m/S	
	Capital cost (per KW)	362.5	$/KW	
	Replacement cost (per KW)	312.5	$/KW	
	O&M cost (Per KW)	7.5	$/yr	
	Hub height	100	m	
	Overall efficiency	26	%	
	Lifetime	20	years	
Solar PV	Rated power	705	KW	Li et al. (2018) and Tribioli and Cozzolino (2019)
	Derating factor(floss)	88	%	
	Capital cost (per KW)	1200	$/KW	

	Replacement cost (per KW)	1200	$/KW	
	O&M cost (Per KW)	4	$/yr	
	Lifetime	20	years	
Battery	Nominal capacity	360	Ah	Jahangir et al. (2020b)
	Nominal voltage	6	V	
	Max charging current (Imax)	18	A	
	Minimum state of charge (SOCmin)	30	%	
	Maximum state of charge (SOCmax)	100	%	
	Round trip battery efficiency(Πbatt)	92	%	
	Capital cost (per KW)	167	$/KW	
	Replacement cost (per KW)	67	$/KW	
	O&M cost (Per KW)	300	$/KW	
	Lifetime	15	years	
converters	Rated power	250–1665	KW	Akhtari and Baneshi (2019)
	Rectifier and inverter Π	90	%	
	Capital cost (per KW)	550	$/KW	
	Replacement cost (per KW)	550	$/KW	
	O&M cost (Per KW)	10	$/yr	
	Lifetime	15	years	
WEC(Pelamis)	Rated power	1000	KW	
	Rated flow speed(m/s)	2.90	m/s	
	Rotor diameter(m)	16	m	
	Rotor swept area(m^2)	201	m^2	
	Rated Cp	0.40		
	Capital cost (per KW)	4.750.000	$/KW	Google Scholar (0000)
	Replacement cost (per KW)	4.200.000	$/KW	
	O&M cost (Per KW)	443.9	$/KW	
	Lifetime	20	years	
	Density seawater	1025	Kg/m^3	
Others	Interest rate	10.5	%	Central Bank of Kenya
	Project life	20	years	
	Bus voltage (DC)	240	V	
	Batteries in string (Nbatt)	20	units	
	Inflation rate	6.8	%	Central Bank Kenya

Table 4- 2 Components technical and economic data

4.3 Model Description

The main objective of this study is to develop a suitable BlockEnergy microgrid model and optimize it to improve availability or reliability. Therefore, the study proposes three energy supply models based on site specific available energy resources for the electrification of standalone BlockEnergy microgrid see Table 4-1. Table 4-1 shows an energy supply models scenarios as follows, energy supply model-A(ESM-A) represents a hybrid of photovoltaic (PV), tidal wave energy (TW), and battery energy storage systems (BESS) used as backup power source in case of PV absence, where TW replaces the conventional diesel generator. In the energy supply model-B(ESM-B) model, here photovoltaic (PV) is replaced with wind turbine (WT) source of energy. Finally, energy supply model – C (ESM-C), all sources of energy are used to generate energy combined. The solar photovoltaic (PV) modules, wind turbines, tidal wave converters, bi-directional system converters are the major components used to develop these models.

Energy supply model	ESM -A	ESM-B	ESM-C
Description	PV-BESS-TW	WT-BESS-TW	PV-WT- BESS-TW

Table 4- 3 Energy supply model designed scenarios

4.3.1 Objective Function Formulation

The main objective of this study was to minimize the annualized system cost (ASC), least cost of energy (LCOE), Net Present Cost (NPC), and energy index reliability (EIR) of the Block Energy microgrid while maintaining optimal energy flow. The three-energy supply model(ESM) models were used to determine the most optimal configuration which will include tidal wave, solar photovoltaic (PV), wind, and battery storage system as the main decision factors.

The objective function applies annualized system cost (ASC) to determine the economic viable cost model for the case study area. The model with the least ASC is observed as the most optimal while meeting all the parameters and constraints. The objective function for the microgrid is the total system cost which includes total capital cost, replacement cost, and operational and maintenance cost of the components.

Function 4.15 represents the main problem objective function for the designed microgrid subject to equality and inequality constraints. The problem function 4.15 was applied in this study to minimize the annualized system cost (ASC) objective function.

$$minimize: ASC \qquad \textbf{(4.15)}$$

$$= F(N_{sol}C_{sol} + N_{wt}C_{wt} + N_{batt}C_{batt} + P_{inv}C_{inv} + N_pP_D + P_{twg}C_{twg})$$

Where C_{sol}, C_{wt}, C_{batt}, C_{inv}, are the cost of solar PV panels (per KW), wind turbines (per KW), battery (per KW) and inverter (per KW) respectively. While N_p is the number of prosumers $and\ C_{twg}$ is the cost of tidal wave (per KW). P_D is the electrical load of prosumers, P_{twg} is the rating of the tidal wave converters, and P_{inv} is the rating of the inverter.

The annualized system cost (ASC) of the installed components has several parts which includes capital and installation cost (C_{acap}), replacement cost (C_{arep}), annual maintenance cost (C_m), operation cost (C_f) and salvage cost (C_{sal}). Therefore, the total ASC of each component can be expressed as follows in equation 4.16, 4.17, 4.18, 4.19 and 4.20:

$$C_{sol} = C_{sol}^{acap} + C_{sol}^{arep} + C_{sol}^{m} - C_{sol}^{sal} \quad \textbf{(4.16)}$$

$$C_{wind} = C_{wind}^{acap} + C_{wind}^{arep} + C_{wind}^{m} - C_{wind}^{sal} \quad \textbf{(4.17)}$$

$$C_{batt} = C_{batt}^{acap} + C_{batt}^{arep} + C_{batt}^{m} - C_{batt}^{sal} \quad \textbf{(4.18)}$$

$$C_{tidal\,wave} = C_{tidal\,wave}^{acap} + C_{tidal\,wave}^{arep} + C_{tidal\,wave}^{m} - C_{tidal\,wave}^{sal} \quad \textbf{(4.19)}$$

$$C_{inv} = C_{inv}^{acap} + C_{inv}^{arep} + C_{inv}^{m} - C_{inv}^{sal} \quad \textbf{(4.20)}$$

The capacity recovery factor (CRF) is used in the annualized system cost to determine the present value of money for each component. Equation 4.21 is a capacity recovery factor equation which was used in determining the net present cost of the microgrid for a period of 25 years.

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad \textbf{(4.21)}$$

Where N was taken as 25 years , a lifetime of solar photovoltaic panel or module , and i is the annual interest rate was taken as 12% of the current central bank of Kenya.

The salvage (S)value was determined at the end of the project lifetime that reduces the total net present cost. Salvage value(S) is the value remaining for each microgrid component after a project's lifetime is completed. This study the salvage cost was modelled using the mathematical formula below.

$$\begin{aligned} salvage\ cost(S) &= replacement\ cost \\ &\times remaining\ lifetime\ of\ the\ component(years) \\ &\times component\ lifetime(years) \end{aligned} \qquad \textbf{(4.22)}$$

The net present costs(NPC) are costs that occur during the project lifecycle with future cashflows discounted to the present using the discount rate. Net present costs (NPC) include the initial cost, replacement costs, operational and maintenance costs.

$$minimize\ (NPC = ASC \times CRF(i, N) \qquad \textbf{(4.23)}$$

Subject to PV_power>0; annual energy demand<PV _ power; Battery power + PV_power.

The optimal configuration is selected based on LCOE and reliability. Equation 4.24 shows the least cost of energy (LCOE) that was used to declare the average price per KWh of the energy generated by the system.

$$LCOE = \frac{ASC\ (\frac{\$}{year})}{total\ useful\ energy\ served(\frac{KWh}{year})} \qquad \textbf{(4.24)}$$

4.3.2 Problem Designed Constraints

The objective function was minimized subject to a set of constraints that must be satisfied with any feasible solution throughout the system operation

1) Power generated

The total power was taken as the summation of solar photovoltaic power(PV), wind power(WT) and tidal wave energy. The battery powerin was given as the summation of the intermittent sources. Equation 4.25 presents the power charging the battery bank, equation 4.26 shows an inequality constraints of energy generation in 24 hours for a period of 365.

$$P_{total}^{k} = N_{pv}P_{pv}^{k}(t) + N_{wt}P_{wt}^{k} \quad \textbf{(4.25)}$$

$$1 \leq k \leq 365, 1 \leq t \leq 24 \quad \textbf{(4.26)}$$

The power generated from each source $P_{gen}(i)$ must be less than or equal to the maximum capacity of the source. Equation 4.26 is an inequality constraint of individual energy generated by each renewable energy source constrained between a minimum and maximum number of solar panels, and wind turbines.

$$P_{gen}(i) < P_{gen;max}(i) \quad \textbf{(4.26)}$$

$$1 \leq N_{sol} \leq N_{sol}^{m}$$

$$1 \leq N_{wt} \leq N_{wt}^{m}$$

Where (i) is number of sources, N_{sol}^{m} is the maximum number of solar PV panels, N_{wt}^{m} is the maximum number of wind turbine.

2) Power balance constraint

The total power P_{total} generated by the intermittent renewable energy sources (RES) sources was ensured to meet the total load demand (P_{demand}), the total power losses (P_{losses}) and storage power ($P_{storage}$) if used. Equation 4.27 was an expression applied to ensure total power or supplied power was greater than the total load demand.

$$P_{total} = P_{demand} + P_{Losses} + P_{storage}\ or\ P_{supply} \geq P_{demand} \qquad \textbf{(4.27)}$$

3) Battery constraints

Expressions 4.28 and 4.29 was used to limit the charging and discharging of the battery energy storage system, while considering the minimum and maximum number of batteries that was used during modelling. Therefore, this study ensured that, at any given time of the microgrid lifetime operations, the inequality constraints expression 4.30 was satisfied.

$$E_B; min \leq E_B(t) \leq E_B; \max or\ SOC\ min \leq SOC \leq SOCmax \qquad \textbf{(4.28)}$$

$$E_B(t+1) = E_B(1-\sigma) \qquad \textbf{(4.29)}$$

$$1 \leq N_{batt} \leq N_{batt'}^{m} \qquad \textbf{(4.30)}$$

where N_{batt}^{m} is the maximum number of batteries

The inequality expression 4.31 was applied to control the back-up generation at any given time. The tidal wave energy generation was controlled on an hourly basis (TW). Where the tidal wave energy(P_{TWg}) *was ensured to be* less than or equal the tidal wave energy converter (TWEC)rated power, P_{TWr} as shown in equation 4.31.

$$1 \leq P_{TWg}(t) \leq P_{Twr}^{max}(t), \qquad \textbf{(4.31)}$$

where $\mathrm{P_{Twr}^{max}(t)}$ is the maximum rating of tidal wave energy converter.

4.3.3 System Reliability Constraints

1. Loss of load probability(LOLP)

Loss of load probability (LOLP) was used to measure the loss of load risk, and where the capacity outages are less than the reserve will not lead to a loss of load. And when a particular capacity outage was greater than the reserve contributed to the overall risk by the amount of $P_j t_j$. Equation 4.32 was used as a constraint in modelling for load reliability index, however, was treated as the second objective function output during system simulation.

$$LOLP = \sum_{j} P_j t_j \tag{4.32}$$

Therefore, equation 4.33 shows the loss of load probability, LOLP, of the system that was taken as less than allowable LOLP reliability index. In this study, equation 4.32 and 4.33 was not applied because the objective was to examine the effects of energy supply on load variability.

$$LOLP\_HP < LOLP\_HPindex \tag{4.33}$$

2. Loss of power supply probability (LPSP)

The loss of power supply probability (LPSP) is a statistical parameter that was applied to measure the system performance with known load. Equation 4.34 was used to determine the probability of power loss caused by low renewable resources or components failure using equation

$$LPSP = \frac{sum((Solar\ PV\ power + windpower + battery\ powerin) - loadpower)}{number\ of\ hours} \tag{4.34}$$

The reliability index is declared in percentages. In this study, 0 reliability was interpreted to mean 100% reliability. Equation 4.35 presents a percentage renewable factor that was applied evaluating renewable energy sources penetration in the system.

$$percentage\ renewable\ factor = \left(1 - \frac{\sum_t^T P\_WEC}{\sum_t^T PV_{power} + \sum_t^T Windpower}\right) \times 100 \quad (4.35)$$

The energy index reliability of the individual energy sources is determined from the expected energy not served (EENS) as follows

$$EIR = 1 - \frac{EENS}{E} \tag{4.36}$$

$$EENS = \sum_{t}^{T} battery\ powerin - batterypower - surplus\ power) * U(t) \tag{4.37}$$

Where U(t) is a step function and is taken zero when total power is more than or equal to load power and it is one if power is deficit in time t.

4.3.5 Operational Strategy

In the proposed ESM above proper energy management is needed to ensure availability or reliability. In the three ESM models tidal wave energy is used on a need basis, especially when wind, PV and BESS fail to meet load demand. The following are steps of operational strategies.

If the total power produced by solar PV panels and wind turbine is sufficient and wind power is less than load, then demand can be served by PV sources only. After satisfying the load, surplus power can be provided to the battery bank and is given as,

$$p_b(t) = p_{pv}(t) - [p_l(t) - p_W(t)]/\eta_{inv} \tag{4.38}$$

where $p_l(t)$ denotes load demand at any time and η_{inv} denotes the efficiency of the inverter. If $P_{sol}(t)$ is the power produced by an individual solar PV panel and Nsol is the total number of solar PV panels, then the total power produced by solar PV panels $p_{pv}(t)$ is given as

$$PV\_power(t) = P_{sol}(t)N_{sol} \tag{4.39}$$

Further, if $P_w(t)$ is the power produced by an individual wind turbine and $N_w(t)$is the total number of wind turbines, then the total power generated by wind turbines $P_{WT}(t)$ can be given as,

$$Wind\_power(t) = P_w(t)N_w(t) \quad \textbf{(4.40)}$$

Further, if $P_{Tw}(t)$ is the power produced by an individual tidal wave converter and $N_{Tw}(t)$is the total number of tidal converters, then the total power generated by tidal converters $P_{Tw}(t)$ can be given as,

$$P_{Tw}(t) = P_{wv}(t)N_{Tw}(t) \quad \textbf{(4.41)}$$

If power generated solely from wind turbines is enough to supply load demand, the remaining power (solar & wind) can be fed to the battery bank. The battery power in this case can be calculated as,

$$p_b(t) = p_{pv}(t) + [p_W(t) - p_l(t)]/\eta_{rectifier} \quad \textbf{(4.42)}$$

where $\eta_{rectifier}$ is the rectifier efficiency.

In both the above-mentioned cases, if $p_b(t)$ is greater than the maximum allowable capacity of battery bank $P_b^{max}(t)$ then excess energy could be dumped or can be given to deferrable loads. Excess or dump energy is obtained as,

$$P_{dump}(t) = P_b(t) - P_b^{max}(t) \quad \textbf{(4.43)}$$

If solar PV panels and wind turbines are not generating adequate power, then balance power can be supplied by the battery and is calculated as,

$$p_b(t) = [p_l(t) - p_W(t)]/\eta_{inv} - p_{pv}(t) \quad \textbf{(4.44)}$$

The available capacity of the battery is calculated as follows:

If $P^k_{Total}(t) = P^k_L(t)$, then the battery capacity remains unchanged, where the input power of DC/AC converter $P^k_L(t) = \frac{P^k_{Total}(t)}{\eta i}$, $P^k_{Total}(t)$ is the load demand of i^{th} hour and K^{th} day.

If the $P^k_{Total}(t) > P^k_L(t)$, then the surplus power, $P^k_{surplus}(t) = P^k_{Total}(t) - P^k_L(t)$, is used to charge the battery and new capacity of battery is obtained by equation (4.3). If the battery state of charge (SOC) reaches 100%, the surplus power will be wasted in a dummy resistive load.

If $P^k_{Total}(t) < P^k_L(t)$ then the battery supplies the shortage in the power and the new battery capacity is obtained by equation 4.45.

In addition, whenever the battery SOC falls below a minimum allowable limit, that is maximum DOD, the microgrid will not operate reliably, and the optimization constraint will be violated. The simulation was performed over a year of operation with one hour time steps. If solar and wind power are inadequate and batteries ($SOC(t) \leq SOCmin$)are also not able to produce the desired power to meet the load demand, then tidal wave supplies power to the load. Tidal wave converter was applied in two ways,

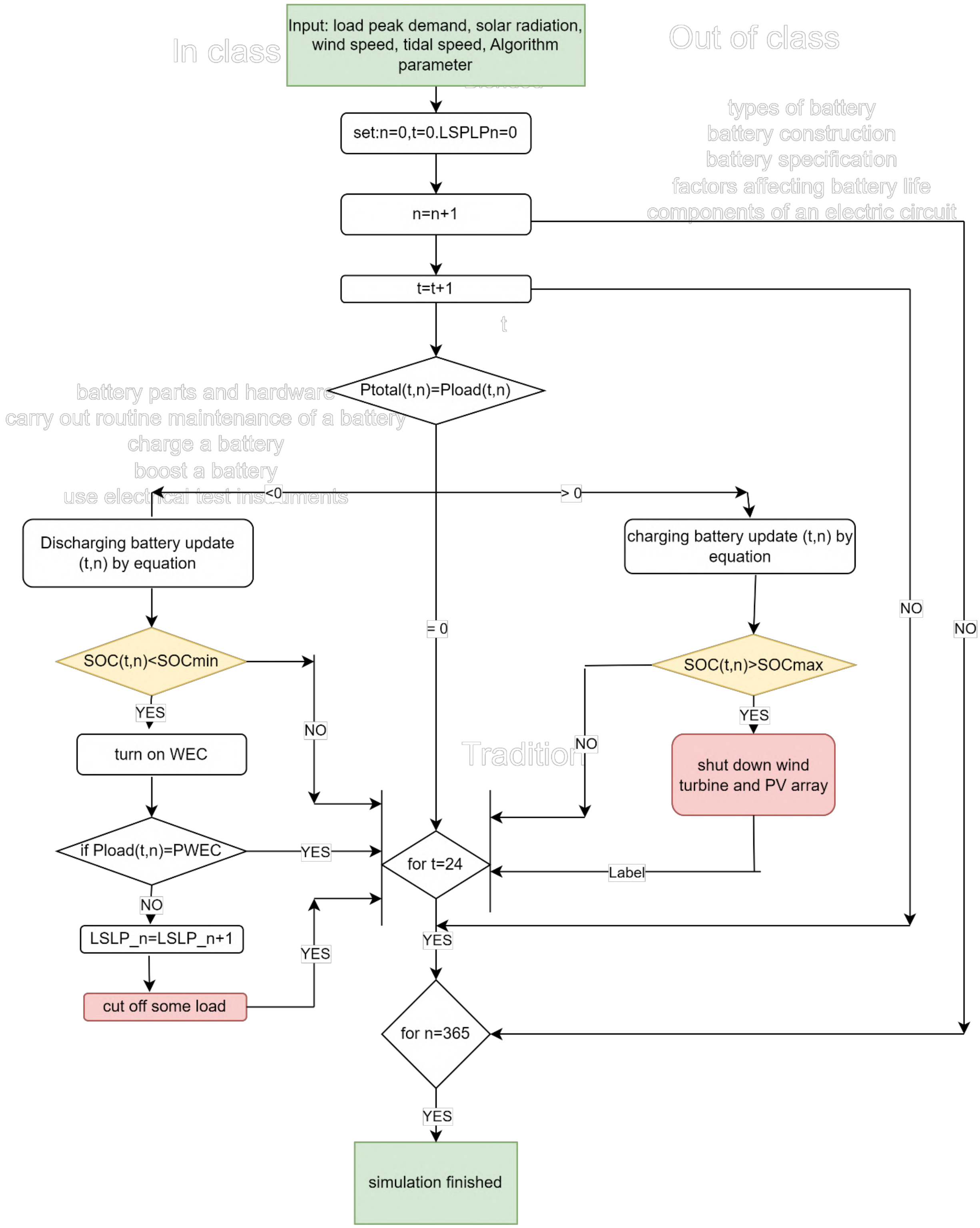
(a) The first way, the load followed the strategy, i.e., whenever it was operated, it generated only the required power to meet the primary load demand. Equation 4.45 shows the power generated by the tidal wave converter, the power generated was determined by deficit supply from the renewable energy sources and battery storage systems.

$$P_{Tw}(t) = p_l(t) - p_W(t) - p_{pv}(t) / \eta_{inv} \tag{4.45}$$

(b) In the second strategy, it operates at rated capacity or minimum load ratio. Equation 4.46 shows that, the converted tidal wave energy rated capacity was used to charge the batteries in the microgrid. In this case tidal converter was operating at rated capacity, and therefore the surplus power was used to charge the batteries.

p_b (t)= 〖[P〗 _Tw (t)-p_l (t)+ p_W (t)]η_rectifier+p_pv (t) (4.46)

The flow chart 4-1 describes the operational strategy of the designed model demonstrated sub-section 4.3.5. This flow chart outlines the steps followed during the modelling and simulation process. In this study the flow chart 4-1 described the required input data used, algorithm parameters, supply reliability and the expected output of the model



Flow chart 4- 1 operational strategy of the designed model

4.4 Optimization of the Energy Supply Model Using PSO

In the literature reviews, it was mentioned that the technical and economic analysis of renewable energy resources are key for efficient minimization. The solution to this requires appropriate and suitable modeling and software tools that can be used to design, analyze, optimize, and perform economic planning. In this study MATLAB2016a software tool was adopted as a platform during the development of the code which was used in formulating the optimization problem by computing the coefficients of the objective function in equation (4.15).

The study adopts particle swarm optimization (PSO) as an optimization technique because of its simplicity, efficiency, reliability, adaptability, forecasting ability, energy demand, unit commitment, and demand management as earlier stated in the literature review. Particle swarm optimization (PSO) is a population – based technique. It applies multiple particles to form the swarm where every particle refers to a possible solution.

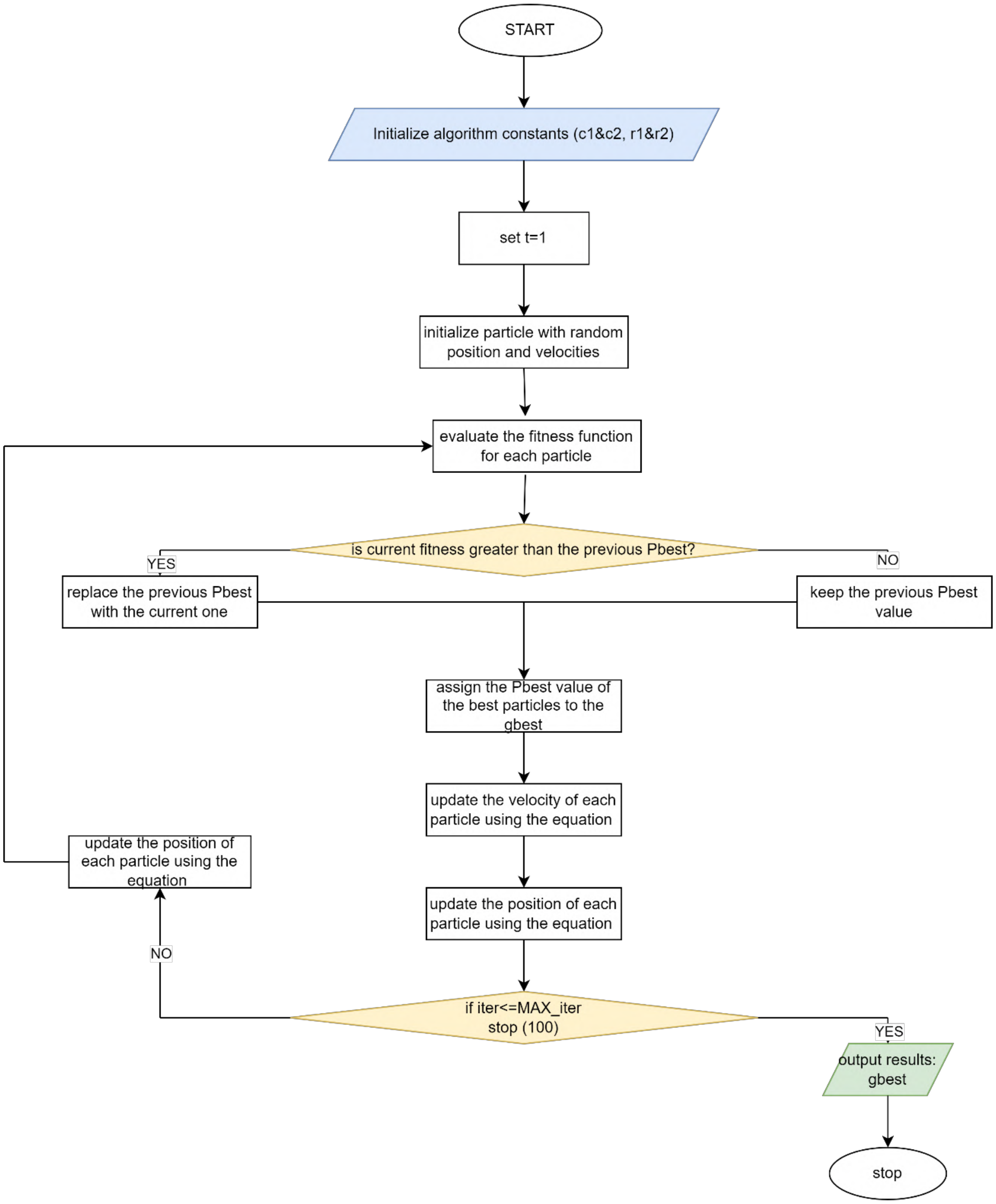
The set of candidate solutions co-exists and cooperates simultaneously. The particles in the swarm fly in the search space, searching for the best solution to land. Here the search space portrays the set of possible solutions, and the swarm of flying particles portrays the changing solution. In the entire iteration of the experiment, every particle maintains its track of personal best solution(optimum) in the swarm.

The two-particle swarm optimization (PSO) parameters are modified, that is the flying speed(velocity) and the position. The particles dynamically change their flying speed in response to their own flying experience and that of their neighbors. Also, the position changes using the information of its current position, velocity, the distance between the current position and personal optimum and the current position and swarm optimum.

The swarm of particles will continue to move towards a possible search space until the global optimum is obtained. The optimization problem is solved using the following particle swarm optimization (PSO) parameters and the sequence is shown in the flowchart 4-2. Flow chart 4-2 shows the steps or procedure applied while simulating the model using particle swarm optimization (PSO) algorithm. This procedure or steps was used to minimize the objective function 4.15 problem to obtain the desired optimum solution in cost and system reliability. In table 4-2 the particle swarm optimization parameters used for initialization of the algorithm are demonstrated. These parameters were applied to initiate the simulation of the designed model for purpose of obtained gbest and local solution.

PSO algorithm	
Dimension of the problem(D)	4
Population size(N)	100
Initial weight (Wmin)	0.1
Final weight (Wmax)	0.9
Maximum iterations (itermax)	10
Weighting factors (C1and C2)	2

Table 4- 4 Particle swarm algorithm parameters



Flow chart 4- 2 Particle Swarm Optimization (PSO) flowchart

Using the particle swarm optimization (PSO) parameters of table 4-2 and procedures in flow chart 4-2, the Algorithm 4.1 illustrates the methodology used in minimizing the annualized system cost (ASC) and the modified objective function with penalty equation 4.15 to optimize the annualized system cost, the number of solar panels, number of wind turbine , maximum power generated from wave energy converter and system reliability.

ESM-PSO Algorithm 4.1

Input: solar radiation data, wind speed data, tidal speed data, solar panel specification data, wind turbine data, peak load demand data, model devices prices and wave energy converter data.

Output: N_SOL, N_WT, N_batt and P_WEC

1. Store SOC_max, SOC_min, population size, dimensions, limits, max_iter
2. Store N_SOLmax=300, N_WTmax=20, N_battmax=1400, P_MI=861.750
3. Compute P_SOL(t) and P_WT(t) applying equation (2.1) and (2.2)
4. Generate a randomly initialized populations using
    i. N_SOL= Lb_sol+rand [0,1] *(Ub_sol-Lb_sol).
    ii. N_WT= Lb_wt+rand [0,1] *(Ub_wt-Lb_wt).
    iii. N_batt= Lb_wt+rand [0,1] *(Ub_wt-Lb_wt).
5. Set iteration (t)=0
6. Calculate the following for initial randomly generated solution (N_SOL, N_WT, N_batt, P_WEC)
7. Compute PV_power(t) and Wind_power(t) using equation (4.7) and (4.8)
8. Perform steps outlined in the operational strategies
9. Calculate the component costs for initial solution by using equations 4.16 through 4.20
10. Minimize the objective function F(ASC) equation 4.15 for initial swarm Pbest.
11. Calculate the fitness value of swarms in the population

$$penalty(i,j) = \left\{ penalty\ function(PP) \times g(i,j)^{g(i,j)<0}_{g(i,j)=0} \right.$$

Where penalty (i, j) is the evaluated cost value of the solution N_SOL, N_WT, N_batt.

```
12. Generate modified objective function for the swarm particles to penalize violated
    constraints
   ASC_OUT=ASC+ penalty (i, j)
13. Iter=1
14. While iter < maxiter
    15. Update individual and global best (pbest and gbest) using the set equations below
          i.   N_SOL= Lb_sol+rand [-1,1] *(Ub_sol-Lb_sol).
          ii.  N_WT= Lb_wt+rand [-1,1] *(Ub_wt-Lb_wt).
          iii. N_batt= Lb_wt+rand [-1,1] *(Ub_wt-Lb_wt).
    16. Minimize the objective function (ASC)equation 4.15 for following step 6
    17. Update the velocity and position of each particle
          $v_i^{t+1} = v_i^t + c_1 r_1 (Pbest_i^t - P_i^t) + c_2 r_2 (gbest_i^t - P_i^t)$
    18. Update the position of each particle using the equation
          $P_i^{t+1} = P_i^t + V_i^{t+1}$
    19. Compute loss of power supply probability (LPSP) using equations 4.30 and 4.31.
    20. Compute least cost of energy (LCOE) using equation 4.32
    21. Update the individual and global best (Pbest and gbest) using equation
          a) N_SOL= Lb_sol+rand [0,1] *(Ub_sol-Lb_sol).
          b) N_WT= Lb_wt+rand [0,1] *(Ub_wt-Lb_wt).
          c) N_batt= Lb_wt+rand [0,1] *(Ub_wt-Lb_wt).
    22. Minimize the objective function (ASC)equation 4.15 for following step 6
    23. Update the velocity and position of each particle
          $v_i^{t+1} = v_i^t + c_1 r_1 (Pbest_i^t - P_i^t) + c_2 r_2 (gbest_i^t - P_i^t)$
    24. Update the position of each particle using the equation
          $P_i^{t+1} = P_i^t + V_i^{t+1}$
    25. Recall and save the gbest solution gained, if there is a better solution.
    26. Iter=iter+1
```

```
27. End While
```

Chapter 5: Results Analysis and Discussion

5.1 Introduction

In this chapter, the results are presented and discussed. The chapter also examines the following performance metrics: the annualized system cost (ASC), loss of power supply probability (LPSP), net present cost (NPC), number of solar panels, number of wind turbine, number of storage batteries, energy index reliability (EIR) and least cost of energy (LCOE) for setting up a reliable and efficient Microgrid in a simulation time step of one hour on a data for a period of one year.

The optimal microgrid annualized system cost is generated using simulation of technical and economic data in Table 4-4 is shown in Figure 5-1. Figure 5-1 demonstrates an energy supply model optimal solution search using particle swarm optimization (PSO). In this figure a distribution of swarms searching for gbest solutions, the concentration of swarms searching for optimal solutions at the pareto fronts locates where the gbest solution was found.

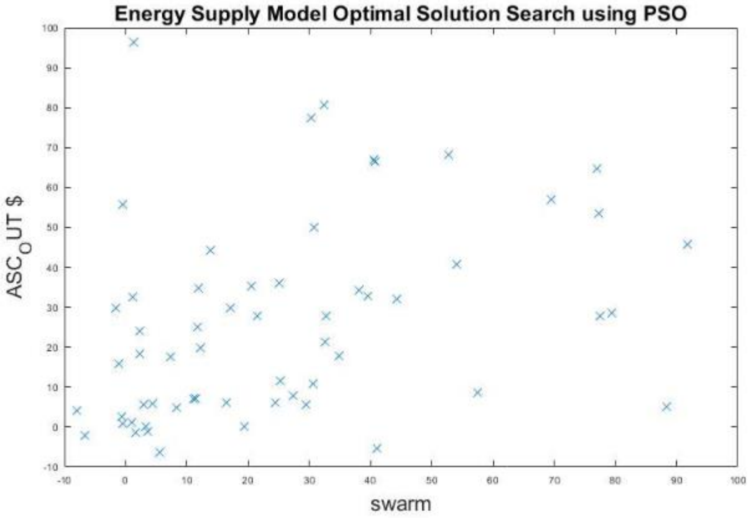


Figure 5- 1 ESM optimal solution using PSO

5.2 Results Analysis

The results of energy supply model were modelled on MATLAB2016a and simulated using the designed particle swarm optimization algorithm. The algorithm used the parameters shown in Table 5-1. The Ant bee colony (ABC) algorithm used a maximum number of solar PV panels, wind turbines and batteries which were 300, 20 and 1400 respectively. For results analysis, this study adopted these numbers to compare the performance of the designed model against anti bee colony (ABC) algorithm. The maximum rating of wave energy converter (WEC) was taken as 1000 kW. The inverter and converter were not taken as a decision variable but rather selected based on peak load demand taken as 1790 kW.

The author refers to the article on feasibility study of an islanded microgrid in rural area consisting of hybrid renewable energy (Singh et al., 2016) Anti Bee Colony (ABC) algorithm results are taken to compare with the results of the ESM-PSO model. The results consist of optimal total number of solar panels, wind turbines, batteries, and a maximum rating of wave energy converter. The feasible and optimal result is selected based on annualized system cost (ASC), net present cost (NPC), and least cost of energy (LCOE).

5.3 Economic Analysis

The designed model results are analyzed based on three performance parameters which are econometric, environmental and equipment technical performance. The performance parameters in econometrics were used to model the annualized system cost (ASC), and least cost of energy (LCOE) using equation 4.15 and 4.32 respectively. Table 5-1 shows the performance of the designed ESM-PSO algorithm and that of ABC algorithm used as the performance baseline of ESM-PSO. The prediction was done in 50 maximum iterations and 500 swarms using particle swarm optimizer.

5.3.1 Least Cost of Energy (LCOE) and Net Present Cost (NPC)

Table 5-1 shows the optimal results of least cost of energy (LCOE) and net present cost (NPC) generated after simulation of energy supply model particle swarm optimization(ESM-PSO) algorithm was 0.4449$/KWh and $33968 respectively. It can be referred to from the table that the comparison results generated by ant bee colony (ABC) algorithm and that of ESM-PSO, demonstrates a better performance for both net present cost (NPC) and least cost of energy (LCOE).

Algorithm	PV (units)	Wind turbine (units)	Wave energy converters (KW)	Batteries (units)	Inverter (KW)	WEC running(h)	ASC(M$/yr)	NPC ($)	LCOE($/KWh)
ESM-PSO	31011	18	114.72	179	861.984	10	68,311.26	33968	0.4490
ABC	250	19	-	1400	115	10	63,006.00	723378	0.173

Table 5- 1 ESM-PSO optimal sizing result

5.3.2 Annualized System Cost

The economics of the designed model components was investigated based on net present value and the annualized system cost, which is tabulated in Tables 5-3, 5-4, and 5-5, for ESM-A representing a hybrid of solar photovoltaic, wave energy converter and batteries(PV-BESS-WEC), ESM-B representing a hybrid of wind, wave energy converter and batteries (WT-BESS-WEC), and ESM-C representing a hybrid of solar photovoltaic, wind, wave energy converter and batteries (PV-WT-WEC-BESS) respectively.

This combination was meant to analyze the most suitable renewable energy hybrid that was economical and reliable and that, the simulated results on annualized system cost for the individual hybrid combinations demonstrated that, out of the three designed models shown in the tables below exist a slight variation which indicated of an efficient and reliable model that is a good candidate of deployment in the case study area.

Table 5-2 shows that ESM-A model recorded an annualized system cost analysis of $/yr 64852.43. This hybrid though moderate to invest and operate, the reliability index approaches 0 and therefore can be the most ideal and economically viable model in the case study area, also the lower NPC predicts the model being superior to that of ABC algorithm(Singh et al., 2016).

Breakdown of ASC obtained for the PV-BESS-TW model using PSO algorithm					
Component	**Capital** **($/yr)**	**Replacement Cost** **($/yr)**	**Maintenance cost** **($/yr)**	**Salvage cost** **($/yr)**	**Total** **($/yr)**
Solar PV	9964	1200	4	240	11408
WEC	40319	4200	443.9	1050	46012.9
Batteries	1797.2	67	300	22.33	2186.53
Inverter	4501.7	550	10	183.3	5245
Total	**56581.9**	**6017**	**757.9**	**1495.63**	**64852.43**

Table 5- 2 ESM-A model annualized system cost analysis

Table 5-3 shows a combination hybrid of ESM-B model that recorded least annualized system cost analysis of $/yr 56903.36. This hybrid though cheap to invest and operate, the reliability index is more than 0 and therefore is not the most ideal and economically viable model in the case study area, also the lower NPC predicts the model being superior to that of ABC algorithm(Singh et al., 2016).

Breakdown of ASC obtained for the WT-TW-BESS model using PSO algorithm					
Component	**Capital** **($/yr)**	**Replacement cost** **($/yr)**	**Maintenance cost** **($/yr)**	**Salvage cost** **($/yr)**	**Total** **($/yr)**
Wind	3076.33	312.5	7.5	62.5	3458.83
WEC	40319	4200	443.9	1050	46012.9
Batteries	1797.2	67	300	22.33	2186.53
Inverter	4501.7	550	10	183.3	5245
Total	**49694.23**	**5129.5**	**761.4**	**1318.13**	**56903.26**

Table 5- 3 ESM-B model annualized system cost analysis

Table 5-4 shows a combination hybrid of ESM-C model that recorded highest annualized system cost analysis of $/yr 56903.36. This hybrid combination is expensive to invest and operate, but the reliability index was approaching 0 and therefore is the most ideal and economically viable model in the case study area, also the lower NPC predicts the model being superior to that of ABC algorithm(Singh et al., 2016).

Breakdown of ASC obtained for the PV-WT-TW-BESS model using PSO algorithm					
Component	**Capital** **($/yr)**	**Replacement cost** **($/yr)**	**Maintenance cost** **($/yr)**	**Salvage cost** **($/yr)**	**Total** **($/yr)**
Solar PV	9964	1200	4	240	11408
Wind	3076.33	312.5	7.5	62.5	3458.83

WEC	40319	4200	443.9	1050	46012.9
Batteries	1797.2	67	300	22.33	2186.53
Inverter	4501.7	550	10	183.3	5245
Total	**59658.23**	**6329.5**	**765.4**	**1558.13**	**68311.26**

Table 5- 4 ESM-C model annualized system cost analysis

Figure 5-2 shows the individual source energy generators pareto analysis on annualized system cost. In this figure 5-2 solar PV source records high annualized system cost of 50%, followed by wave energy converter and batteries at 21% each. The annualized system cost for wind shows a low cost below 10% , pareto fronts simulates graph above 10% represention. Therefore it is not viable to invest on wind for this case because there is low generation in wind energy.

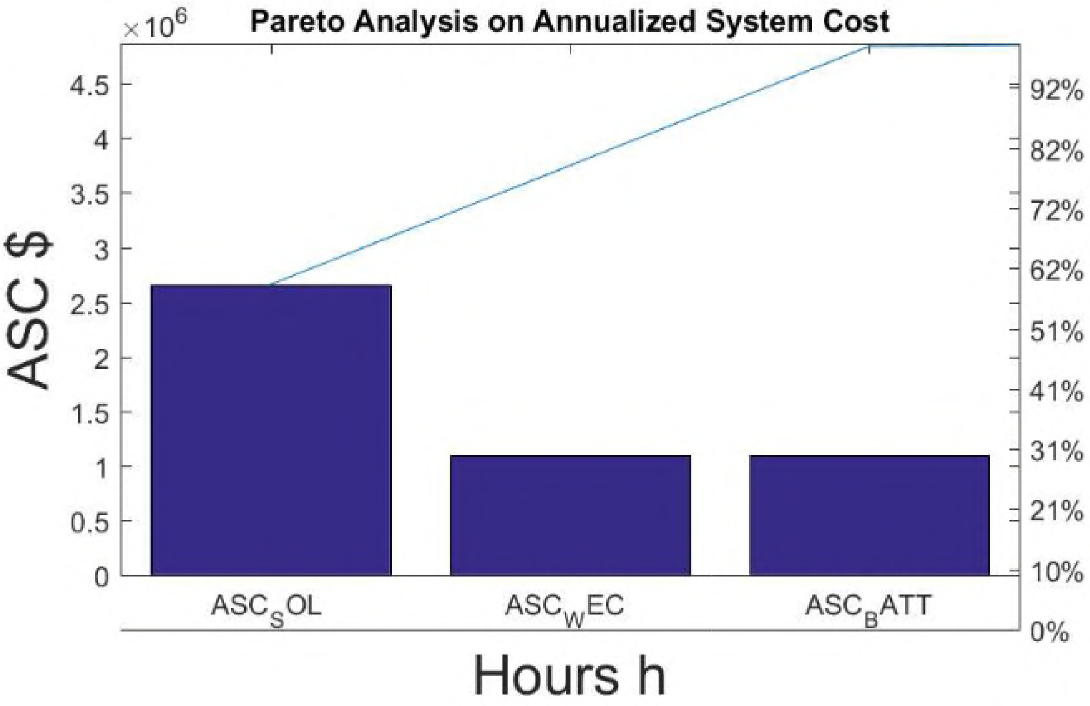


Figure 5- 2 Pareto analysis on annualized system cost

Figure 5-3 is a normal distribution of the annualized system cost for the three-energy model supply. The annualized system cost for the three model is seen to skew to the right demonstrating a positive distribution with a mean of 63355.65 and standard deviation of 4776.043.

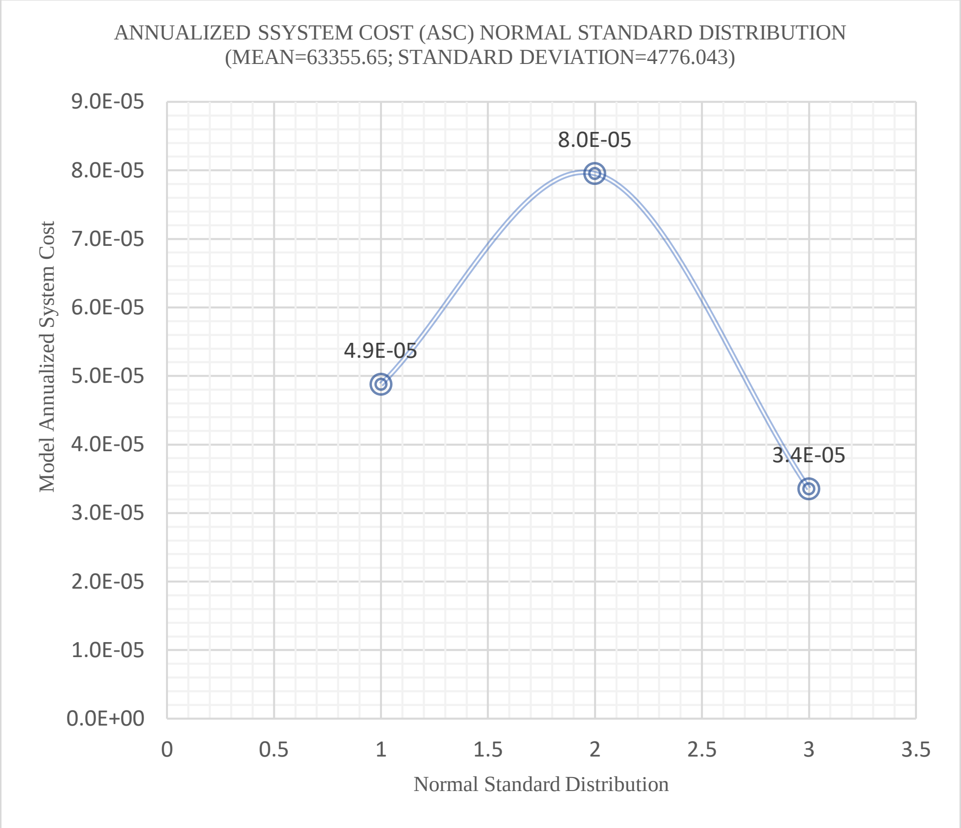


Figure 5- 3 Normal standard distribution

5.4 Microgrid Components

In chapter two of this study, the author highlighted that a reliable microgrid consist of hardware which includes Solar panels, wind turbines, converters or inverters, a storage bank (Batteries), and a diesel generator or Biomass for backup in case of power blackouts. In this design table 5-2 provide the simulated data of the individual number of components used to design the microgrid. The data shows superior optimal solution, if compared to ABC algorithms used by other researchers(Singh et al., 2016). However, the number of solar PV panels is demonstrated higher in the proposed model than the ABC algorithm.

5.4.1 Household Load Demand Analysis

The data collected from the 110 households and the dump loads summed up to 330.215KW per day which was higher than the minimum multi-tier framework (MTF) Tier 5 which is stated as 8KW per day. The power consumption was estimated to be 4610.47 KWh per day. Figure 5-4 shows a load duration curve for Wasini island. The figure presents a plot of maximum load obtained from the island survey conducted and a minimum load obtained from the multi-tier framework, tier 5 as the model designed parameter of enabling energy access for the island. Figure5-4 was critical in determining the expected energy supplied where load follows the installed capacity of the microgrid.

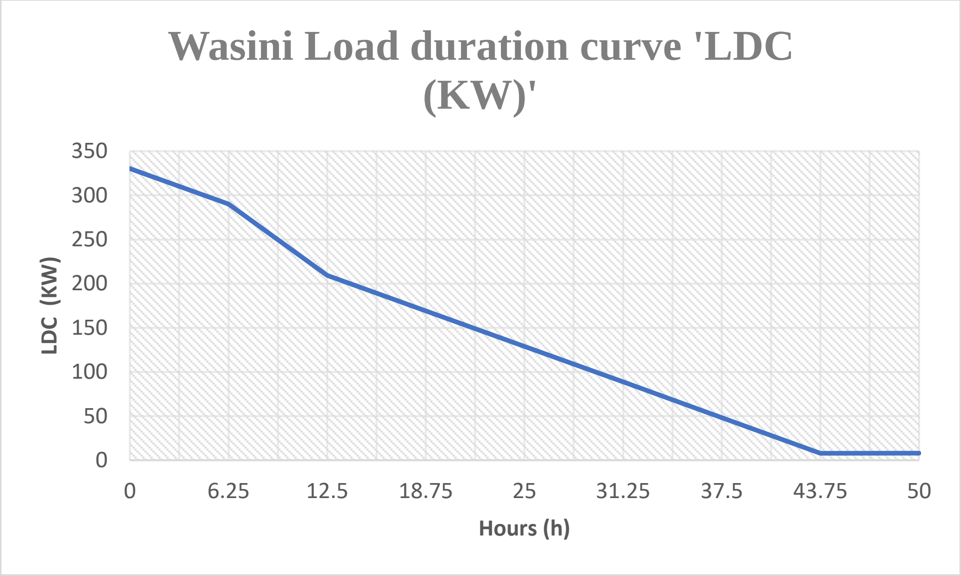


Figure 5- 4 Wasini load duration curve

Figure 5-5 presents a polynomial load duration curve for the load demand collected from the survey. The data indicated a linear model Polynomial following that followed a f(x) = p1*x + p2. Where x is normalized by mean 25 and std 17.12, coefficients (with 95% confidence bounds) of p1 = 110.8 (101.2, 120.4), p2 = 129.2 (120.2, 138.3). The goodness of fit obtained a sum of square error (SSE): 923.1, root-square: 0.9916, Adjusted R-square: 0.9904 and root mean square error (RMSE): 11.48.

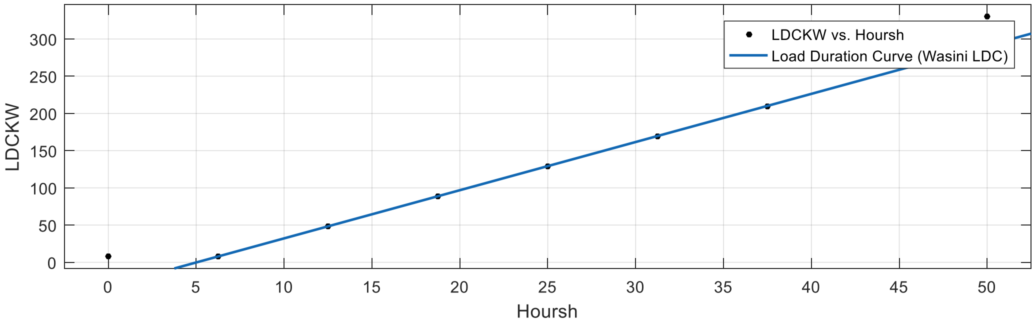


Figure 5- 5 Polynomial load duration curve

Figure 5-4 and 5-5 was used to determine expected energy supply (EES) and expected energy not supplied (EENS). The area under the load duration curve represents the expected energy supplied, in priority, solar photovoltaic and wind energy generators was given the first consideration, while tidal wave energy was given the second priority. When solar and wind energy generators was selected to meet the load demand, an expected energy not supplied (EENS) and expected total energy not supplied (ETENS) was determined as 3213.373929KWh and 3448.853791 KWh respectively. Therefore, the expected energy supplied by the two intermittent sources was generated as 475.8105836KWh.

In considering, the second priority, an expected energy not supplied(EENS) and expected total energy not supplied (ETENS) is given as 275.3535702 KWh and 393.7230982 KWh respectively. While the value for expected energy supplied(EES) by tidal wave energy source is given as 3055.130693 KWh.

5.4.2 Energy Analysis per Resource

Table 5-5 represents energy analysis results for both anti-bee colony(ABC) and energy supply model particle swarm optimization(ESM-PSO). Table 5-5 shows compared simulated results of energy produced from the constituent components generated by anti-bee colony (ABC) algorithm and energy supply model particle swarm optimization (ESM_PSO) algorithm. The output results of the simulated designed model differ with the anti-bee colony (ABC) algorithm in terms of renewable energy resource contributions.

The energy supply model particle swarm optimization (ESM-PSO) defers with ant-bee colony algorithm on the amount of power generated by wind turbines. The energy generated by wind turbines in these models, the anti-bee colony (ABC) was seen generating 76009KWh/year and energy supply model particle swarm optimization generating 5.8228 KWh/yr solar. However, both algorithms have similar output characteristics where solar photovoltaic resource leads in energy generation and heavy contributor in the two models. Also, the designed model was seen to generating 710626.95KWh/yr excess energy not served to the loads, while the anti-bee colony(ABC) model generated 5139KWh/yr in excess.

The energy generated from solar photovoltaic source, in both cases it was found to be sufficient in meeting load demand , but because of its variability it was making the system not reliable. It is from this argument that tidal wave energy was essential during the design of the model to address the variability nature of wind and solar. In reference to table 4-1 on classified 110 household load demand per day, the designed model meets the total energy demand with solar PV, wind, and battery.

Table 5-5 demonstrates elements of better performance when the total served energy exceeds the total demand energy for Tier1, Tier2 and Tier3 of the multi-tier framework (MTF) distribution. Also, it’s important to note that the surplus energy or electricity of 710626.03 generated represents 90% of the total load served. In contrast, the ABC algorithm excess energy generated is 5139KWh/yr representing 1.4% of the total energy served.

Energy Resource	ABC KWh/yr	ESM-PSO KWh/yr
Solar	463201	715867.839
Biomass	326	-
Wind	76009	5.8228
Wave energy converter	-	2753.2842
Total energy served	362795	718626.95
Excess electricity	5139	710626.03

Table 5- 5 Energy analysis by ABC and ESM-PSO

5.5 Robustness Test

The purpose of this test was to determine the effectiveness of ESM-PSO algorithm obtained results. In reference to ABC algorithm where a total number of 30 runs was performed to study the effectiveness of the model, the designed model was also subjected to the same test runs. Table 5-6 demonstrates the average, maxima, minima value of ASC and standard deviation of the 30-test conducted which makes ABC algorithm slightly more effective than the designed model with a difference in standard deviation of 115.92.

Algorithm	Mean value	minima	maxima	Standard deviation
ESM-PSO	64,661,	63794	65480.55	409.36
ABC	64180.05	63006	64755.6	293.44

Table 5- 6 Statistics of the result

5.6 Reliability Analysis Test

In this test, the model considered a randomized number on the stochastic load characteristics to determine the loss of power supply probability(LPSP) using equation(4.34), energy index reliability (EIR) using equation (4.36-4.37), and percentage renewable factor(%) equation(4.35) to obtain a statistical parameter which was 8% showing that the reliability of the system annually $(8\% \times 365) = 29 days$ will have no generations from the renewable energy sources and therefore, wave energy will supplement the deficit energy.

The percentage renewable energy factor was used to determine the amount of energy coming from tidal wave energy sources as compared to the renewable variable sources. Using equation (4.35) the percentage renewable factor is obtained as 99.71% a demonstration of high renewable intermittent penetration in the microgrid.

The computed expected energy not served (EENS) for individual energy source is in Figure 4-3 which shows a pareto analysis of an energy index reliability. The figure shows that, energy index reliability (EIR) for the energy generator sources is below 10% in the pareto analysis. This represents a high fluctuation of renewable energy generation. Applying equation 4.36 and 4.37, the energy index reliability (EIR) was simulated to generate a value of 0.9 or 90% system capacity reliability. This value demonstrates the system

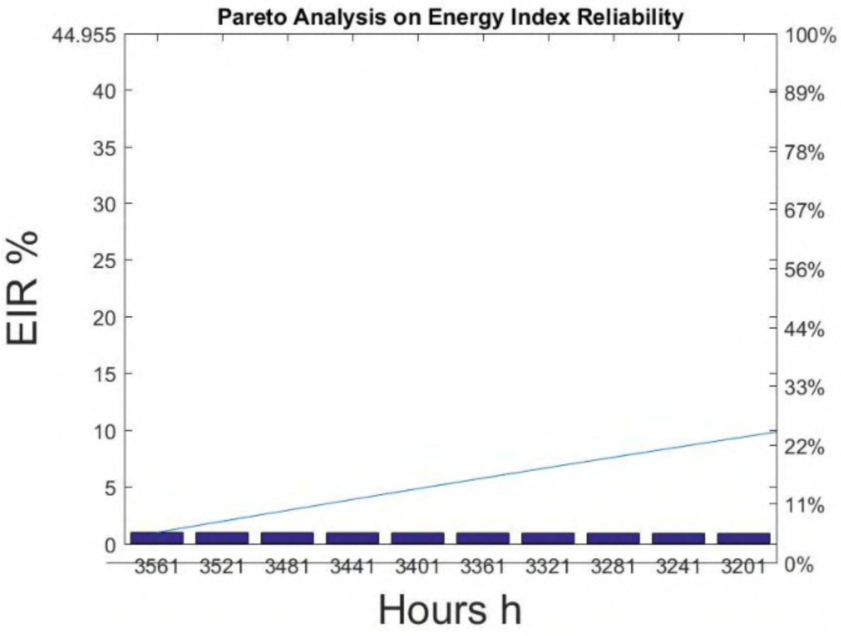


Figure 5- 6 Energy index reliability

Chapter 6: Conclusion and Future Work

In this chapter, conclusion is drawn from the results presented and recommendations are made on how to improve the energy supply model running on a particle swarm optimization algorithm.

6.1 Conclusion

In this thesis a bottom-up stochastic energy supply model algorithm which can be applied in modelling and optimize a standalone hybrid renewable energy sources microgrid with a tidal wave energy as a backup has been developed. The algorithm can manage supply of power from individual source generator through an operational strategy. The operational strategy encourages the utilization of intermittent sources (solar and wind generators) and battery storage before initiating tidal wave energy to meet the supply deficit.

The simulation results reveal that the optimal annualized system cost of the system not only depends on system technical data specification devices, site load demand and but also depends on site specific weather data. The annualized system cost is $ /yr 66,836.49 with a reliability index of 0.1. Without the use of penalty function and constraints, the annualized cost increases and the system becomes unreliable. It can be deduced from the results that, this optimal microgrid satisfies the load demand without violating any constraints. The load was varied to check on its robustness and it revealed that, only 29 days of the year was not receiving power from renewable energy sources and that need was supplemented by wave energy converters.

The simulations results obtained by energy supply model using particle swarm optimization have been compared with ABC algorithm. The designed algorithm proved to be better compared to results generated from ABC algorithm baseline study. The computational time of the algorithm was proved to be better compared to ABC algorithm baseline study.

6.2 Future Work

Hybrid renewable energy supply in this study included tidal waves that have similar performance characteristics as conventional energy source. Tidal wave energy in the microgrid was designed based on cost and reliability criteria. In future studies, system uncertainty such as stochastic generation or load variations might be considered, by performing adequacy evaluation in reference to probabilistic methods.

The stochastic generation or load variations may be modeled using time-series methods. The short coming of the model failed to include prosumer during simulation and therefore may form basis of considering prosumer in future model designs. The stochastic generation or load variation may be simulated using artificial intelligence and genetic algorithm to compare the performance of ESM-PSO in future studies.

In future studies, complicated design that would include emission modelling, and environmental factors is an area to focus on, as opposed to the current model which used technical and economic factors of the system. This objective is critical to determine level of renewable energy penetration towards the contribution of a free carbon world.

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Strathmore University Institutional Scientific and Ethical Review Committee (SU-ISERC)

Final Decision

This is to certify that the application for ethics clearance submitted by:

Principal Investigator: Mr. Chiro, Javan Kambu

Reference number: SU-ISERC1823/23

For Study: "Energy supply optimization of the Microgrid"

Was reviewed and received the following status: "approved"

Reviewer Comments

The SU-ISERC wishes you all the best with this research undertaking.

22 August 2023 16:41:37

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

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Date of Issue: **25/August/2023**

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ENERGY NEED ASSESSMENT AND PREFERENTIAL CHOICE SURVEY OF RURAL/ISLAND PEOPLE IN WASINI/KISITE MPUNGUTE- KENYA

Questionnaire To Households

I, **Javan Kambu Chiro**, a master's student from SU – Strathmore University, Nairobi, Kenya. Am currently working on my master's thesis evaluating the potential for optimizing micro-grids in rural islands villages. For that, I am conducting a survey to better understand the energy use among households in the island, and their preferences. I'm particularly interested in the possibility of using household Nanogrids and microgrids for blockchain electricity generation. The blockchain grids could provide electricity for productive use such as provision desalinated clean water, flake ice production, fish preservation, powering schools and hospitals. In addition to serving as the basis for my academic work, my study will be used in a larger feasibility study by local partner such as REREC in kwale county and any other counties.

Your help and support in filling up this questionnaire would greatly help in my endeavor. I thank you in advance for your time and cooperation in this matter.

More information on the project can be obtained from **Dr. Vincent Omwenga** researcher and project coordinator, **Dr. Kennedy Rono** researcher and project supervisor school of computing and engineering sciences, SU-Kenya (kronoh@strathmore.edu, vomwenga@strathmore.edu)

Instructions

- Please, use (✓) to indicate your answer among the options provided for each question (one or more).
- Please write N/A if the question is not applicable to you.

Rank your preferences (1,2,3...) where required – 1 as the highest rank and so forth.

A. Household General Information

1. State the size of the house. Tick (✓) appropriately.

Home size	(✓)
Small	
Medium	
Large	
Mansions	

2. State the number of bedrooms for the house above. Tick appropriately (✓)

Number of bedrooms	(✓)
1≥ 2	
3 ≥ 4	

5 ≥ 6	
6 ≥ 12	
Others (please specify)	

3. Provide the members of the household.

Members	**Number**
Adults	
Children between twelve and below 18	
Children below 12	
Total	

4. State the average monthly income in the household? Mark (✓) appropriately

Average monthly income	(✓)
Less than Ksh.10000	
10000≥ 15,000	
15,000≥ 25,000	
25,000≥ 35,000	
35,000≥ 45,000	
45,000≥ 55,000	
Greater than 55,000	

5. State the source of income for your household? **Mark (✓) appropriate**

Source of income	(✓)
Fisher	
Farmer	
Teacher	
Health workers Driver	
Boat rider	
Carpenter	
Other (specify)	

6. State the source of lighting? Mark (✓) appropriately

Electricity	☐
Kerosene lamp	☐
Solar devices	☐
Battery torch	☐
Others (please specify)	

7. State the source of cooking fuel? Mark (✓) appropriately

Description	(✓)
Firewood	
Electricity	
Gas	
Charcoal stove	
Improved jiko (jiko Koa)	
Others (please specify)	

8. State the educational status of the family (for members above 18 years)? Mark (✓) appropriately.

Members	Basic knowledge (print name & signature	Primary (level 1-5)	High school (level 6-10)	College or university	Other (specify
Male					
Female					

B. ASSESSMENT OF ENERGY CONSUMPTION

Household Electrical Appliances

1. Do you own a cooking appliance? YES or NO. If yes mark with (✓) the type and state the number.

Items	**TYPE**	**QUANTITY OF ITEMS**
Kettle		
Microwave		
Induction hob		
Dish washer		
Bread toaster		
Rice cooker		
Blender		
Air fryer		
Others (please specify)		

2. State the type of lighting appliances used for lighting? Please, tick (✓) appropriately and state the numbers of appliances

Items	**TYPE**	**QUANTITY OF ITEMS**
Incandescent Lamp		
Fluorescent Lamp		
Compact Fluorescent Lamp		
Sodium Vapor Lamp		
Mercury Vapor Lamp		
Halogen Lamp		
Metal Halide Lamp		
Neon Lamp		
LED Lamp		
Laser lamp		
Others (please specify)		

3. State the type of electronic appliance used for entertainment? please choose appropriately. Hence state the quantities of appliances.

Electronic Type	**TYPE**	**QUANTITY OF ITEMS**
Flat TV		
Video recorder		
DVD		
Radio		
Amplifier		
Soundbars		
Projectors		
Satellite dishes		
Others (please specify)		

4. Do you own work-related electronic appliances? YES/NO. If yes Please tick (✓) appropriately, hence, state the number.

Reasons	**TYPE**	**QUANTITY OF ITEMS**
Desktop		

Laptop		
Printer		
Scanner		
Photocopier		
Other, specify:		

5. Do you own food or post harvesting preservation cold chain appliances? YES/NO. If yes, tick (✓)appropriately hence, state the quantities.

Cold appliances	**TYPE**	**QUANTITY OF ITEMS**
Chest freezers		
Chillers		
Refrigerator		
Cold room		
Others (please specify)		

6. Do you own a laundry washing machine? YES/NO. If yes pleases tick (✓) appropriately and state, the quantities.

Laundry appliances	**TYPE**	**QUANTITY OF ITEMS**
Washing machine		
Electric iron		
Water heaters		
Cloth dryer		
Others (please specify)		

7. Do you own any of the following telecommunication electronic appliances? Tick appropriately.✓ and hence state the quantities.
   1) Smartphone ☐
   2) Tablets ☐
   3) Landline ☐
   4) Internet server ☐
   5) Others (please specify)
8. Is this house fitted with an air conditioning unit? YES/NO. if yes Please tick (✓) the type appropriately and state the number of units fitted.

Air conditioning appliances	**TYPE**	**QUANTITIES OF ITEMS**
Fly		
Fan		
Air conditioner		
Humidifier		
De-humidifier		

Thank you for taking part in filling in the survey form.

ENERGY NEED ASSESSMENT AND PREFERENTIAL CHOICE SURVEY OF RURAL/ISLAND PEOPLE IN WASINI/KISITE MPUNGUTE- KENYA

Questionnaire to School

I, **Javan Kambu Chiro**, a master's student from SU – Strathmore University, Nairobi, Kenya. Am currently working on my master's thesis evaluating the potential for optimizing micro-grids in rural islands villages. For that, I am conducting a survey to better understand the energy use among households in the island, and their preferences. I'm particularly interested in the possibility of using household Nanogrids and microgrids for blockchain electricity generation. The blockchain grids could provide electricity for productive use such as provision desalinated clean water, flake ice production, fish preservation, powering schools and hospitals. In addition to serving as the basis for my academic work, my study will be used in a larger feasibility study by local partner such as REREC in kwale county and any other counties.

Your help and support in filling up this questionnaire would greatly help in my endeavor. I thank you in advance for your time and cooperation in this matter.

More information on the project can be obtained from **Dr. Vincent Omwenga** researcher and project coordinator, **Dr. Kennedy Rono** researcher and project supervisor school of computing and engineering sciences, SU-Kenya (kronoh@strathmore.edu, vomwenga@strathmore.edu)

Instructions

- Please, use (✓) to indicate your answer among the options provided for each question (one or more).
- Please write N/A if the question is not applicable to you.

Rank your preferences (1,2,3...) where required – 1 as the highest rank and so forth.

A. School General Information

1. What is the school size? Tick (✓) appropriately.

Home size	(✓)
Single stream	
Two streams	
Three streams	
Four streams	
Others (please specify)	

2. What is the number of Classrooms. Tick (✓) appropriately

Number of bedrooms	(✓)
1≥ 2	

3 ≥ 4	
5 ≥ 6	
6 ≥ 12	
Others (please specify)	

3. What is the school population?

Members	**Number**
Teachers	
Pre-school	
Primary	
Junior secondary school	
Total	

4. What is the school's average monthly expenditure on electricity? Tick (✓) appropriately.

Average monthly income	(✓)
Less than Ksh.100,000	
100,000≥ 150,000	
150,000≥ 250,000	
250,000≥ 350,000	
350,000≥ 450,000	
450,000≥ 550,000	
Greater than 550,000	

5. What is the school's source of lighting? Mark (✓)

Electricity	☐
Kerosene lamp	☐
Solar devices	☐
Battery torch	☐
Others (please specify)	

6. Do you have a school feeding program? YES/NO. If yes, state the source of cooking fuel. Please tick (✓) appropriately.

Description of cooking fuel	**TYPE**
Firewood	
Electricity	
Gas	
Charcoal stove	
Improved jiko (jiko Koa)	
Others (please specify)	

7. Do you have evening classes? YES/NO. If yes, please tick (✓) appropriately the starting time.

Time	(✓)
4pm to 6 pm	
6 pm to 8 pm	
8pm to 10 pm	
4 am to 6pm	
Others (please specify)	

B. ASSESSMENT OF ENERGY CONSUMPTION

School Electrical Appliances

1. Which type of cooking appliance, is owned by the school for cooking? Please tick (✓) appropriately.

Items	TYPE OF COOKING APPLIACES (✓)	QUANTITIES
Kettle		
Microwave		
Induction hob		
Dish washer		
Bread toaster		
Rice cooker		
Blender		
Air fryer		

2. Which type of lighting appliances do you mostly use for lighting? Please, tick (✓) appropriately and state the number.

Items	TYPE (✓)	QUANTITIES
Incandescent Lamp		
Fluorescent Lamp		
Compact Fluorescent Lamp		
Sodium Vapor Lamp		
Mercury Vapor Lamp		
Halogen Lamp		
Metal Halide Lamp		
Neon Lamp		
LED Lamp		
Laser lamp		

3. What type of electronic appliance do you normally use as a teaching aid? please mark (✓) appropriately and state the number.

Electronic Type	TYPES (✓)	QUANTITIES
Flat TV		
Video recorder		
DVD		
Radio		
Amplifier		
Soundbars		
Projectors		
Satellite dishes		

4. What type of work-related electronic appliances do the school own? Please tick (✓) appropriately and state the number.

Reasons	TYPE (✓)	QUANTITIES
Desktop		
Laptop		
Printer		
Scanner		
Photocopier		
Other, specify:		

5. Do the school own a food or post harvesting preservation cold chain appliances? YES/NO. If yes, tick (✓) appropriately and state how many.

Cold appliances	**TYPE (✓)**	**QUANTITIES**
Chest freezers		
Chillers		
Refrigerator		
Cold room		

6. Do the school own the following types of telecommunication electronics appliances? YES/NO. if yes tick (✓) appropriately, hence state the number.
    1) Smartphone ☐
    2) Tablets ☐
    3) Landline ☐
    4) Internet server ☐
    5) Others (please specify)
7. Is the school fitted with air conditioning units? YES/NO. if yes, please tick (✓) type appropriately, hence state the number.

Air conditioning appliances	**TYPE (✓)**	**QUANTITIES**
Fly		
Fan		
Air conditioner		
Humidifier		
De-humidifier		

Thank you for taking part in filling in the survey form.

ENERGY NEED ASSESSMENT AND PREFERENTIAL CHOICE SURVEY OF RURAL/ISLAND PEOPLE IN WASINI/KISITE MPUNGUTE- KENYA

Questionnaire to Hospital or Dispensary

I, **Javan Kambu Chiro**, a master's student from SU – Strathmore University, Nairobi, Kenya. Am currently working on my master's thesis evaluating the potential for optimizing micro-grids in rural islands villages. For that, I am conducting a survey to better understand the energy use among households in the island, and their preferences. I am particularly interested in the possibility of using household Nanogrids and microgrids for blockchain electricity generation. The blockchain grids could provide electricity for productive use such as provision desalinated clean water, flake ice production, fish preservation, powering schools and hospitals. In addition to serving as the basis for my academic work, my study will be used in a larger feasibility study by local partner such as REREC in kwale county and any other counties.

Your help and support in filling up this questionnaire would help in my endeavor. I thank you in advance for your time and cooperation in this matter.

More information on the project can be obtained from **Dr. Vincent Omwenga** researcher and project coordinator, **Dr. Kennedy Rono** researcher and project supervisor school of computing and engineering sciences, SU-Kenya (kronoh@strathmore.edu, vomwenga@strathmore.edu)

Instructions

- Please, use (✓) to indicate your answer among the options provided for each question (one or more).
- Please write N/A if the question is not applicable to you.

Rank your preferences (1,2,3...) where required – 1 as the highest rank and so forth.

A. Hospital/Dispensary General Information

1. State the rank of local hospital? Rank as 1=community facility, 2=health dispensary, 3=health centres, 4=county hospital, 5= county referral hospital, 6=national referral hospital.

Home size	**1**	**2**	**3**	**4**	**5**	**6**
Small						
Medium						
Large						
Mansions						
Others (please specify)						

2. Does the health Centre or dispensary have patient wards and offices? Yes/No. If yes, tick (✓) the number of offices and patient wards.

Number of wards/offices	**Wards and offices**
1≥ 2	
3 ≥ 4	
5 ≥ 6	
6 ≥ 12	
Others (please specify)	

3. What is the hospital average monthly expenditure on electricity?

Average monthly income	**Electricity bill**
Less than Ksh.100,000	
100,000≥ 150,000	
150,000≥ 250,000	
250,000≥ 350,000	
350,000≥ 450,000	
450,000≥ 550,000	
Greater than 550,000	

4. What is the source of lighting? Mark (✓)

Electricity	☐
Kerosene lamp	☐
Solar devices	☐
Battery torch	☐
Others (please specify)	

5. Do you have a feeding program for patients? Yes/No. If yes, state the source of cooking fuel. Please tick appropriately.

Description	**Yes**	**NO**
Firewood		
Electricity		
Gas		
Charcoal stove		
Improved jiko (jiko Koa)		
Others (please specify)		

6. Do you offer in-patient? YES/NO. If yes, state the capacity and please tick (✓) appropriately.

B. ASSESSMENT OF ENERGY CONSUMPTION

Health facility Electrical Appliances

1. State the type of cooking appliance owned for cooking in the hospital? Please tick (✓) appropriately and state the number if any.

Items	(✓)	**Quantity of items**
Kettle		
Microwave		
Induction hob		
Dish washer		
Bread toaster		
Rice cooker		
Blender		
Air fryer		
Others (please specify)		

2. Which type of lighting appliances do you mostly use for lighting? Please, tick (✓) appropriately and state the number.

Items	(✓)	**Quantity of items**
Incandescent Lamp		
Fluorescent Lamp		
Compact Fluorescent Lamp		
Sodium Vapor Lamp		
Mercury Vapor Lamp		
Halogen Lamp		
Metal Halide Lamp		
Neon Lamp		
LED Lamp		
Laser lamp		
Others (please specify)		

3. What type of electronic appliance do you normally use for diagnosis? please tick (✓) appropriately and state the number.

Electronic Type	(✓)	**Quantify of items**
Centrifuge		
Ultrasound/probe		
microscope		
Analyzer		
Electrosurgical unit		
Surgical motors		
Colonoscope		
Others (please specify)		

4. What type of work-related electronic appliances do the health facility own? Please tick (✓) appropriately and state the number.

Reasons	(✓)	**Quantify of items**
Desktop		

Laptop		
Printer		
Scanner		
Photocopier		
Other, (please specify)		

5. Do the health facility own vaccines preservation cold chain appliances? If yes, tick (✓) appropriately and state how many.

Cold appliances	(✓)	**Quantity of items**
Chest freezers		
Chillers		
Refrigerator		
Cold room		
Others (please specify)		

6. Does the health facility own the following telecommunication electronics appliances? YES/NO. If yes, please tick (✓) appropriately hence state the number.
   1) Smartphone ☐
   2) Tablets ☐
   3) Landline ☐
   4) Internet server ☐
   5) Others (please specify)
7. Is the health facility fitted with an air conditioning unit? YES/NO. if yes please tick (✓) the type appropriately and state the number.

Air conditioning appliances	(✓)	**Quantity of items**
Fly		
Fan		
Air conditioner		
Humidifier		
De-humidifier		
Others (please specify)		

Thank you for taking part in filling in the survey form.

RESEARCH CONSENT FORM
Energy supply optimization of the microgrids: A case of wasini island

This consent form provides information for potential research participants to understand how the processing of their personal data will be conducted for the purpose of this research project, which is subject to Data Protection Act (DPA)2019. Please sign at the bottom to indicate that you have read and understood how your personal data will be processed, your related rights, and that you consent to this processing as described below.

We are conducting the processing of personal data related to this research project based on your consent. The study will use your electric household appliances data primarily for the purposes of this research project. If the results of this research indicate that further studies are beneficial for the island, we may process your personal data for the purpose of extending our research in this field/area. You will be informed before the further compatible processing takes place.

HOUSEHOLD APPLIANCES DATA USED

The study intends to collect the following categories of personal data: The size of the house, The number of occupants, Household lightings, Electric cooking appliances, Washing machines, Mobile phones, Radios, Television. As a safeguard to protect your privacy, we pseudonymize (key-code) your household data and the principal researcher will have access through a code.

RECIPIENTS OF YOUR HOUSEHOLD APLIANCES DATA

The purpose of this data is to assist in validating the proposed study in **Energy supply optimization of microgrids** with specificity in rural Islands, and fulfillment of partial completion of my master's course requirements.

YOUR RIGHTS

Under the data protection ACT, 2019 and its implementing laws at national level, you have the following rights, with the conditions and limitations set out in PART IV of the DPA:

1) To obtain confirmation that your data is being processed, as well as access to and a copy of your personal data.
2) To obtain correction of your personal data.
3) To obtain erasure of your data if you submit a reasoned request.
4) To obtain portability of your data.
5) To obtain restriction of your data (which means we limit the access to your dataset) if you submit a reasoned request.
6) To withdraw your consent at any time.

When you withdraw your consent, we will not collect additional information related to you. We may also erase the personal data we already collected. This will happen only if its erasure does not render impossible or seriously impair the achievement of the objectives of this research project. To exercise your rights, please use the contact information below to submit a request. When you submit a request, please indicate your name, the name of this study topic, your reasons for making the request, if necessary, and other details you think will be useful for us to comply with your request.

ADDITIONAL INFORMATION

Your personal data will be retained for a period of 2 years after the study is completed. If you have any concerns about how your personal data is being handled, use the address below to contact us. If you are not satisfied with our reply and how we protect your personal data, you can contact the data protection authority in the country or in another relevant jurisdiction for this processing activity, pursuant to the conditions of PART IV DPA.

CONTACT INFORMATION IF YOU HAVE QUESTIONS OR CONCERNS REGARDING DPA

SECRETARIAT

ETHICAL REVIEW COMMITTEE

STRATHMORE UNIVERSITY

Email: vomwenga@strathmore.edu

CONSENT SIGNATURE AND DATE

Print Name: ____

Signature: ____

Date: ____

Strathmore
UNIVERSITY

22nd August 2023

Mr Chiro Javan Kambu,
javan.chiro@strathmore.edu

Dear Mr Chiro,

RE: Energy Supply Optimization of the Microgrid: A Case of Wasini Island

This is to inform you that SU-ISERC has reviewed and **approved** your above **SU-masters** research proposal. Your application reference number is **SU-ISERC1823/23.** The approval period is from **22nd August 2023 to 21st August 2024.**

This approval is subject to compliance with the following requirements:

i. Only approved documents including (informed consents, study instruments, MTA) will be used.
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by SU-ISERC.
iii. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to SU-ISERC within 72 hours of notification.
iv. Any changes anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to SU-ISERC within 72 hours.
v. Clearance for the export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to the expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days of completion of the study to SU-ISERC.

Before commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology, and Innovation (NACOSTI) https://research-portal.nacosti.go.ke/ and obtain other clearances needed.

Yours sincerely,

Mr Ambrose Rachier,
Chairperson; SU-ISERC

STRATHMORE UNIVERSITY INSTITUTIONAL
SCIENTIFIC AND ETHICAL REVIEW COMMITTEE
(SU-ISERC)
23-Aug-2023
Email:ethicsreview@strathmore.edu
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