# Feasibility and sensitivity of an Electrical power system utilizing to ensure sustainable development at offshore area of Bangladesh.

A Thesis

Presented to the

**Institute of Energy Technology**

In Partial Fulfillment of the Requirements for the Degree of

**Master of Engineering in Institute of Energy Technology**

by

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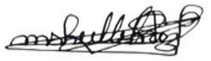
# DECLARATION

I hereby declare that the thesis entitled **"Feasibility and Sensitivity of an Electrical Power System to Ensure Sustainable Development in Offshore Areas of Bangladesh"** is an original work completed by me under the supervision of Professor Dr. Md. Azad Hossain.

This research explores the potential for implementing sustainable electrical power systems in offshore areas of Bangladesh. It highlights the use of renewable energy sources, including wind, solar, and biogas power while assessing their technical, economic, and environmental implications. A sensitivity analysis is performed to understand how factors such as resource availability, costs, and environmental limitations affect system efficiency and decision-making processes. The results aim to support the development of sustainable energy infrastructure in Bangladesh, aligning with the global Sustainable Development Goals (SDGs).

I confirm that this thesis has not been submitted elsewhere for any degree or qualification. All data in this research has been collected through verified sources, including electricity office, weather office and various energy office.

Signature of Candidate



**Samshut Tibriz**

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This thesis stands as a testament to the contributions and support of everyone mentioned here. I dedicate this work to the advancement of sustainable energy systems, hoping it contributes to a brighter future for offshore regions in Bangladesh.

# ABSTRACT

This article delves into the potential of various renewable energy technologies on NijhumDwip a tranquil island in the Bay of Bengal. It explores the practicality and sensitivity assessment of establishing an electrical power system powered by renewable energy aiming to support sustainable development and implement charging stations for fishing boats in NijhumDwip, Bangladesh. The research emphasizes the use of renewable energy sources such as solar, wind, and biogas power to fulfill the energy needs of this isolated island while minimizing environmental repercussions.

A thorough sensitivity analysis assesses the impact of critical variables, including resource availability, system costs and policy frameworks on the effectiveness and sustainability of the system. The results suggest that integrating renewable energy systems in NijhumDwip can provide dependable and sustainable electricity for local communities and maritime operations. Establishing renewable-powered charging stations for fishing boats presents an opportunity to lessen fuel reliance, cut down on carbon emissions and encourage eco-friendly fishing methods. This study presents valuable recommendations for policymakers and energy planners to create sustainable energy solutions specifically designed for the distinct challenges of NijhumDwip, aligning with Bangladesh's aspirations for green energy and sustainable development. Given the island's isolation, there is a notable lack of transmission infrastructure and modern facilities, making it an ideal candidate for renewable energy sources like solar, wind and biogas energy—potentially reducing its carbon footprint to near zero.

Using HOMER software, various configurations of hybrid renewable energy systems were optimized based on system sizes, combinations of renewable energy sources, and other critical parameters. The total Net Present Cost (NPC) for this hybrid energy system was calculated at $5,149,628.00, with an impressive Cost of Energy (COE) of $0.216, which is quite reasonable considering the system's clean nature, ultimately protecting the island's biodiversity.

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| | |
|---|---|
| BPDB | Bangladesh Power Development Board |
| AC | Altering Current |
| ETAP | Electrical Transient Analyzer Program |
| COE | Cost Of Energy |
| GHGs | Greenhouse Gases |
| GDP | Gross Domestic Product |
| Gob | Government of Bangladesh |
| HOMER | Hybrid Optimization Model for Electric Renewable |
| EPCD | Environmental Pollution Control Department |
| IEA | Internal Energy Association |
| IDCOL | Infrastructure Development Company Limited |
| IPPs | Independent Power Producers |
| IRR | Internal Rate of Return |
| NASA | National Aeronautics & Space Administration |
| MATLAB | Matrix Laboratory |
| NPC | Net Present Cost |
| NREL | National Renewable Energy Laboratory |
| PSMP | Power System Master Plan |
| PV | Photo Voltaic |
| RE | Renewable Energy |
| SDG | Sustainable Development Goal |
| SREDA | Sustainable & Renewable Energy Development Authority |
| SHS | Solar Homer System |
| UNDP | United Nations Development Programmer |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

NijhumDwip is a small but ecologically important island nestled in the southern coastal area of Bangladesh. The area features a vibrant fishing community that heavily relies on the abundant marine resources surrounding it.Unfortunately, despite its stunning landscapes and economic prospects, the island grapples with significant challenges, largely due to its isolation and insufficient infrastructure. The lack of a dependable electrical power system has stunted development, making it difficult for residents to engage with modern energy services, efficiently run their businesses and adopt sustainable fishing practices. Currently, fishing boats on NijhumDwip are reliant on diesel fuel, which is not only costly but also harmful to the environment and a contributor to greenhouse gas emissions. Additionally, the absence of local charging facilities has hampered the transition to energy-efficient electric boats, limiting modernization efforts in the fishing sector.

The escalating environmental concerns and rising energy demands in the area urgently call for solutions that prioritize sustainable and renewable energy. Bangladesh has an abundance of renewable energy resources, particularly solar, wind, and biogas that are ideally suited for island communities like NijhumDwip. Utilizing these resources offers a pathway to resolve the island's energy issues while also advancing national objectives for clean energy and sustainable development. However, to bring these systems to life, it’s essential to undertake a comprehensive analysis of their feasibility, which includes assessing energy resource availability, economic viability, and environmental impacts.

Conducting a sensitivity analysis is equally important to understand how changes in key variables—such as fluctuations in renewable energy resource availability, system costs and shifts in government policies—can influence the performance and success of these renewable energy systems. This study aims to provide valuable insights through both feasibility and sensitivity analyses, seeking to create a reliable, cost-effective, and environmentally friendly electrical power system for the people of NijhumDwip.

This research also aligns with Bangladesh's commitment to the Sustainable Development Goals (SDGs), especially SDG 7 (affordable and clean energy), SDG 13 (climate action), and SDG 14 (life below water) [12][19]. By targeting a renewable energy-based electrical framework, which encompasses charging stations for fishing boats, the study tackles the interconnected objectives of enhancing energy access, lowering carbon emissions, and nurturing sustainable livelihoods.

Overall, this context emphasizes the urgent necessity to investigate innovative and sustainable energy solutions for NijhumDwip, setting a precedent that could inspire similar initiatives in other remote and underserved areas of Bangladesh and beyond.

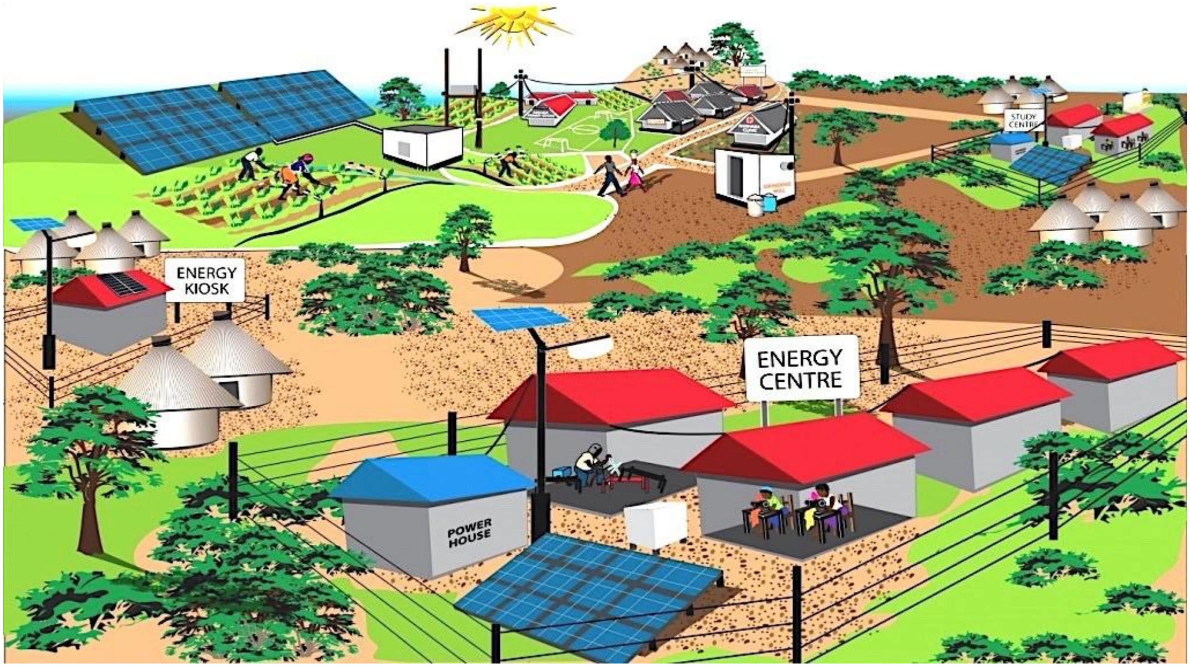



**Figure 1.1: Rural electrification based on renewable energy**

In certain developing countries, rural regions often rely on fossil fuel based power generation, like diesel, for their electrification needs resulting in elevated costs. To address this energy dilemma and satisfy electricity requirements in these areas,offgrid electrification powered by renewable sources emerges as a more viable alternative solution. A widely embraced approach for offgrid electrification is the solar home system (SHS), which has long catered to the fundamental electrical needs of households9 [36][41]. However, SHS is not economically feasible for multiple residences and small enterprises due to inherent technical challenges. Recently, the introduction of minigrids worldwide addresses this issue by facilitating more extensive electrification in rural locales [4][5]. A solar minigrid primarily generates electricity through solar power, complemented by other renewable and conventional energy sources, and distributes it via poles and wiring infrastructure e to serve households, businesses, and institutions within a designated area. Unlike traditional energy systems, hybrid minigrid frameworks based on renewable resources offer an eco-friendly and cost effective energy solution with enhanced reliability and power quality in isolated locations.

**Figure 1.2: Conventional type Fishing boat (CFB) in Bangladesh**

Diesel-based Conventional Fishing Boats (CFBs) in Bangladesh contribute significantly to the fishing industry but have notable environmental effects, particularly related to fuel use and emissions. NOx contributes to the formation of smog and acid rain, negatively affecting air quality and aquatic ecosystems. Spilled diesel creates a thin film on the water surface, which disrupts the exchange of oxygen between air and water, harming marine organisms. Bilge water, often mixed with diesel, oil and other contaminants, is sometimes discharged directly into the sea, polluting coastal and marine ecosystems. Diesel engines produce significant noise, which can disrupt marine life, especially species sensitive to sound, like dolphins and certain fish. Pollution and habitat destruction indirectly affect the food chains, reducing fish populations and biodiversity in the long term. Charging-powered fishing boats are a game-changing solution for sustainable fishing in Bangladesh and other regions. They drastically reduce environmental damage by eliminating emissions, water pollution and noise pollution while promoting the use of renewable energy. While challenges like battery disposal and manufacturing impacts remain, these can be mitigated through proper management, recycling systems, and technological advancements.

Moreover, a hybrid energy system (HES) can tap into additional renewable resources like wind, hydro, and Biogas energy. This option is especially beneficial for regions where the likelihood of grid expansion remains minimal in the foreseeable future.The deployment of hybrid minigrid systems entails significant complexities and challenges, contributing to a substantial l rate of project failures. Numerous studies have been conducted globally regarding HES, particularly focusing on hybrid solar minigrid systems for rural electrification. However, most of these investigations concentrate on techno economic feasibility [16]. For the successful design, implementation, and operation of minigrid systems, it is imperative to analyze technical issues, including challenges, at analysis phase before implementation. Therefore, emphasizing the technical evaluation of such systems at a detailed level is essential to ensure their effective functioning.

## 1.2 Motivation of the Study

The growing global focus on renewable energy and sustainable development is encouraging countries, including Bangladesh, to seek innovative energy solutions for remote and underserved areas. NijhumDwip, a secluded island in Bangladesh, holds significant potential for socioeconomic improvement but is currently constrained by inadequate energy infrastructure. The island’s economy largely relies on the fishing industry, which predominantly uses diesel-powered boats. This reliance not only increases fuel expenses but also leads to environmental harm and limits operational efficiency.

Transitioning to renewable energy systems, such as charging stations for electric fishing boats, could revolutionize NijhumDwip's energy landscape. The coastal regions of Bangladesh are rich in renewable resources like solar, wind, and tidal energy. By harnessing these resources, the island can overcome its energy hurdles while supporting the nation’s commitment to sustainability and the Sustainable Development Goals (SDGs). Nonetheless, effective implementation necessitates thorough feasibility studies and sensitivity analyses to ensure that these systems are reliable, economical, and adaptable to varying conditions.

### 1.2.1. Energy Access for Remote Communities

The residents of NijhumDwip currently grapple with limited electricity access, which hampers both their quality of life and economic prospects. By developing a renewable energy-based power infrastructure, we can provide the community with a consistent, reliable, and sustainable energy supply.

### 1.2.2. Modernization of the Fishing Industry

The fishing industry is heavily dependent on outdated, diesel-powered boats that drive up operational costs and contribute to environmental harm. By introducing renewable energy charging stations for electric fishing boats, we can reduce reliance on fossil fuels, cut greenhouse gas emissions, and improve fishing efficiency.

### 1.2.3. Environmental Conservation

NijhumDwip, with its rich biodiversity, is particularly susceptible to the effects of climate change. Shifting to renewable energy sources will significantly lower carbon emissions, helping to safeguard the island's delicate ecosystem.

### 1.2.4. National and Global Sustainability Goals

This initiative aligns with Bangladesh's renewable energy objectives and supports its commitment to Sustainable Development Goals (SDG) 7 (affordable and clean energy), SDG 13 (climate action), and SDG 14 (sustainable use of marine resources).

### 1.2.5. Replication Potential

Successfully implementing renewable energy systems on NijhumDwip could create a blueprint for other isolated islands and coastal areas in Bangladesh, promoting a broader adoption of sustainable energy practices.

This study is driven by the aim to build a sustainable and resilient energy infrastructure for NijhumDwip, addressing the challenges its residents and fishing sector confront, while also championing environmental sustainability. By pinpointing viable solutions and assessing the sensitivity of key factors, this research intends to offer valuable insights for policymakers, energy planners, and researchers to expedite the energy transition in remote areas like NijhumDwip.

## 1.3 Renewable Energy Scenario in Bangladesh

Bangladesh's commercial energy landscape is diverse and includes resources such as indigenous natural gas, coal, imported oil, liquefied petroleum gas (LPG), imported liquefied natural gas (LNG), imported electricity, and hydroelectric power. Biomass contributes around 25% to the primary energy mix, while the remaining 75% comes from commercial sources. Natural gas alone represents roughly 54% of this commercial energy, which includes 13% from imported LNG [2][3]. In the current year, Bangladesh is projected to import approximately 10.49 million metric tons of crude and refined petroleum products.Additionally, renewable energy solutions such as Solar Home Systems (SHS) are being harnessed in both grid-connected and off-grid areas. Currently, the combined capacity of renewable energy sources, including solar and wind, stands at around 964.17 MW, with power generation from these plants at about 0.69 MW [5][9]. The electricity generated through biomass gasification methods amounts to 0.4 MW.In terms of energy consumption, the average per capita energy use in Bangladesh is around 335 kg of oil equivalent (kgoe), while electricity generation per capita is approximately 602 kWh. Notably, the country enjoys a 100% electricity access rate, although this figure remains lower than that of neighboring South Asian countries. The total primary energy supply in Bangladesh is estimated to be about 57.27 million tons of oil equivalent (MTOE). Of this, natural gas and LNG together account for 41%, biomass comprises 25%, and petroleum oil makes up 18%, with the remainder deriving from coal, LPG, renewable energy, and electricity imports [13].

When considering commercial energy, the total estimated amount is around 42.95 MTOE, with natural gas and LNG contributing a combined share of 54%. Petroleum oil represents 24%, while the rest accounts for sources like coal, LPG, renewable energy, and electricity imports [18].

**Table1.1:List of operational mini-grids in Bangladesh**

| Name of the Project | Capacity(kWp) | Area |
|---|---|---|
| 650 kWp Solar Mini-grid Pilot Project | 650 | Sunamganj |
| PGELSolarMini-gridProject | 100 | Chittagong |
| Shouro Bangla Solar Mini-grid Project | 140 | Narsingdi |
| GHELSolarMini-gridProject | 100 | Cox'sBazar |
| HBPLSolarMini-gridProject | 140 | Rajshahi |
| SEBLSolarMini-gridProject | 180 | Bhola |
| GEALSolarMini-grid | 160 | Kurigram |
| AVASolarMini-grid | 150 | Rajshahi |
| SolargaoSolarMini-gridProject | 130 | Sirajgong |
| Super Star Solar Mini-grid Project | 228 | Manikganj |
| PELSolarMini-gridProject | 210 | Kushtia |
| Uddipan-2Mini-gridProject-2 | 160 | Faridpur |
| Solar Electro Bangladesh Ltd. Mini-gridProject-2 | 250 | Shariatpur |
| Solar Electro Bangladesh Ltd. Mini-gridProject-3 | 250 | Shariatpur |
| EnvisEnergyLimitedMini-grid Project | 250 | Sirajgonj |
| BritBanglaTradeInitiativesLtd. Mini-gridProject | 250 | Gaibandha |
| Blue Marine Energy LimitedMini-gridProject | 250 | Cox'sBazar |
| EastecLtd.Mini-gridProject | 250 | Chapainawabganj |
| Vincen G-Tech Ltd. Mini-grid Project | 250 | Jamalpur |

### 1.4 Present State of the Problem

NijhumDwip, a secluded island in southern Bangladesh, relies heavily on fishing and agriculture for its residents' livelihoods. While this island holds considerable economic promise, its geographic isolation and inadequate access to reliable sustainable energy present notable challenges. These issues are intensified by the rising energy needs of the community and the adverse environmental effects of traditional energy methods. Here's a closer look at the current situation:

#### 1.4.1. Inconsistent Electricity Supply

Due to its remote setting, NijhumDwip has very limited connectivity to the national power grid. The island predominantly depends on diesel generators and fossil fuel-based energy systems, which are costly, inefficient, and detrimental to the environment. This unreliable power supply hampers economic activities and impacts the overall quality of life for the island's inhabitants.

#### 1.4.2. Reliance on Fossil Fuels for Fishing

Fishing is the cornerstone of NijhumDwip's economy, yet most fishing boats operate on diesel engines. The rising cost of diesel significantly undermines the profitability of fishing ventures. Additionally, the use of fossil fuels not only contributes to greenhouse gas emissions but also threatens the island's rich biodiversity and natural resources.

#### 1.4.3. Environmental Fragility

NijhumDwip's low-lying landscape makes it exceptionally susceptible to the consequences of climate change, such as rising sea levels and severe weather conditions. The ongoing dependence on fossil fuels exacerbates global emissions and heightens risks to the island's delicate ecosystem [41].Addressing these challenges is critical for securing a sustainable future for the community of NijhumDwip.

#### 1.4.4. Exploring Renewable Energy Potential

NijhumDwip possesses significant opportunities for renewable energy generation, especially through solar, wind, and tidal sources [21]. However, the full potential is not being realized, primarily due to insufficient technical expertise, lack of financial backing, and a need for strategic planning in developing renewable energy infrastructure.

#### 1.4.5. Lack of Charging Facilities for Fishing Boats

The local fishing industry faces a substantial challenge as there are no facilities available for charging electric fishing boats. This limitation obstructs the shift from diesel to renewable energy-powered vessels. By establishing charging stations powered by renewable energy, it would be possible to cut operating costs, decrease emissions, and modernize the fishing sector, yet this crucial infrastructure is currently missing.

### 1.4.6. Economic and Social Hurdles

The significant upfront costs associated with renewable energy systems, along with a shortage of policies designed for remote areas like NijhumDwip, pose challenges to the adoption of sustainable energy practices. Furthermore, a lack of community awareness and technical training exacerbates the difficulty in transitioning to renewable energy solutions. The current situation in NijhumDwip highlights an urgent need for a cohesive and sustainable energy strategy. To tackle these challenges effectively, it's essential to conduct a thorough feasibility study and sensitivity analysis aimed at creating a renewable energy-based electrical system and charging infrastructure tailored to the island's specific conditions. This initiative seeks to connect the existing energy issues with the promise of renewable energy, ultimately fostering sustainable growth in NijhumDwip.

## 1.5 Literature Review

Since the mid-1980s, researchers around the world have been working tirelessly on developing hybrid systems. Over time, researchers have already proven that hybrid energy systems are ideal for remote locations. Compared to traditional fossil fuels, the cost of power generation has dropped thanks to optimization strategies. Professor Park proposed hybrid power generation systems and ship operation control in a study of power generation using seven solar cells. According to Nehrir's study on the performance of wind/solar power generation systems in Matlab, using electric water heaters as secondary loads made systems using only renewable energy more economical. Many studies have been done on different combinations of hybrid systems. Motin and Co. proposed an energy-saving hybrid system of solar and wind power. Ashok created a model using quasi-Newtonian method to generalize in India to provide the lowest cost electricity. Srinivasan investigated the economic viability of cooking with biogas and the associated benefits. In their study, Rahman et al. focused on a hybrid system using solar photovoltaic resources and biogas to reduce domestic demand in rural Bangladesh. Rajbongshi, Borgohain and Mahapatra used HOMER to propose the optimization of a hybrid renewable energy system of PV, biomass, and diesel to act as a grid station for rural electrification in India. Castellanos et al. focused on integrated renewable energy for electricity generation from solar photovoltaic and biogas in rural areas of West Bengal, India. Mahalakshmi and Latha used HOMER software to evaluate the economics of an Indian textile mill and demonstrated a hybrid solar and biomass renewable energy system. This system stops environmental degradation. Shahzad et al. proposed a technoeconomic feasibility analysis of an off-grid solar-biomass-renewable energy hybrid system for rural electrification in Pakistan using HOMER software. Gwavuya and Co. investigated energy consumption from biogas in rural Ethiopia and highlighted the benefits of using biogas plants. Bond and Templeton investigated a decommissioned biogas plant and highlighted the need for research into efficient anaerobic processes. Schmidt's study showed that while regional grids with photovoltaic (PV) systems are preferred in the Brazilian Amazon, it is economically feasible to convert diesel systems with a maximum output of 50 KW to renewable hybrid systems. Sarkar and Co. have been working to explore the potential of solar energy utilization in Bangladesh's telecommunications sector. Sowed and Co. use micro-concentrated solar energy, which uses small solar collectors to concentrate sunlight and convert it into heat. In their study of Bangladesh's current energy situation and renewable energy potential, Monju and Ullah said, Ahmed et al. In their study, they discussed how to increase renewable energy in Bangladesh and suggested some key factors to mitigate the current power shortage. Ullah et al. proposed hybrid energy for grid-connected power generation that would have a positive impact on Bangladesh's environment. Islam and co highlighted various aspects of renewable energy including policy issues, research activities, etc. before concluding that there is a dearth of renewable energy experts. Shakir et al. suggested locations for the most efficient solar photovoltaic systems in Bangladesh based on factors such as sunshine duration, solar radiation, and type of aircraft. Called for measuring Nepal's potential using long-term data before switching to renewable energy for electricity generation. Researchers Nazir et al. conducted a study proposing a micro-hydro power plant and solar power system and analyzed it using MATLAB and HOMER. The study concluded that the system has better environmental impact despite having a higher initial cost. Carlos Luis Guedes Valente ET al.17] demonstrated the differences between hybrid and conventional fossil fuel systems and argued that hybrid systems are superior in small villages in Brazil. In a review article, PragyaNema et al. propose to model a hybrid solar-wind system and evaluate its cost-effectiveness in remote locations. A hybrid system to generate electricity from renewable energy sources was presented by Mondor et al. Nandi and Ghosh expressed hope for a hybrid system combining solar, photovoltaic and wind energy in Bangladesh despite the high cost of energy. Mohibullah, Bhardwaj and Garg used environmentally friendly HOMER software to generate electricity from a combination of solar, wind and biogas in a remote area of western Uttar Pradesh, northern India. In India where biomass is considered the best source of energy, Mishra, Panigrahi and Kothari used a hybrid renewable energy source including wind, solar and biomass energy. Nfah investigated biogas/photovoltaic system for rural areas in Cameroon. Introducing biogas should reduce the production cost of the hybrid system. HOMER software was used for the analysis. According to Nguyen, Pham, Nguyen, Le, and Van, the cost of generating the required electricity using conventional diesel fuel in Vietnam is 1.6 times higher than the cost of using renewable biomass energy. SoumyaMandal et al., in their study on the prospects of a solar PV/biogas/diesel generator hybrid energy system in off-grid areas of Bangladesh, highlighted a hybrid energy system configuration consisting of solar PV, biogas generator, diesel generator, and energy storage. Previous literature surveys have not conducted any studies on the combination of solar PV, wind, and biogas in isolated islands of Bangladesh. This study focuses on the utilization of solar PV, wind, and biogas as crossover energy sources to mitigate the electricity demand in such areas.The growing global emphasis on energy accessibility, sustainability, and minimizing greenhouse gas emissions has spurred advancements in off-grid power generation systems. These plants, powered primarily by renewable energy sources, offer dependable and eco-friendly energy solutions, particularly in remote or underserved regions. This literature review explores significant studies, developments, and emerging trends in the design and implementation of off-grid power plants.

**Conclusion**

The available literature highlights the significant potential of off-grid power plants in overcoming energy access challenges while fostering sustainability. With advancements in renewable energy technologies, energy storage solutions, and system optimization tools, the development of efficient and dependable off-grid systems is gaining momentum. Nonetheless, there are obstacles to navigate, including high initial investment costs, energy intermittency, and gaps in technical expertise. Addressing these issues requires policy support, financial incentives, and active community participation to secure long-term viability. Future research should concentrate on integrating new technologies and expanding off-grid systems to sustainably fulfill global energy needs.

### 1.6 Objectives

The goal of a Renewable Energy Power Plant (REPP) is to create, develop, and enhance systems that harness renewable energy sources like solar, wind, hydro, biomass, geothermal, and ocean energy to produce electricity. This initiative aims to decrease dependence on fossil fuels, lessen environmental harm, and play a vital role in the global shift toward sustainable energy.

**The main objectives are:**

1) To establish a self-sufficient energy system tailored to the specific needs and resources of the region.
2) To identify the most suitable combination of renewable energy sources Utilize optimization techniques to identify the best configuration for maximum efficiency and minimal cost.
3) To identify and propose charging infrastructure for electric vehicles, including fishing boats, to transition away from diesel-powered transport.
4) To Study the impact of seasonal fluctuations in renewable energy generation assess the integration and reliability of backup systems to ensure consistent energy availability.

# CHAPTER 2

# DESIGN METHODOLOGY

## 2.1 Introduction

The proposed methodology for determining the optimal hybrid power system design is explained at the beginning of this chapter. A methodology has been developed to select the optimal renewable energy based hybrid power plant design. The Bureau of Meteorology and other reliable sources provide various important data. The input parameters are sent to HOMER for optimization and the ideal configuration of the hybrid energy system is determined by collecting various required data.

## 2.2 Methodology

A hybrid energy system combining solar photovoltaic system with wind and biogas is advantageous because electricity generated solely by solar photovoltaic system or wind generators, though both are available at the study site, is not reliable enough to meet the load needs of an independent house[21]. One reason is due to the intermittent nature of covering the area. A hybrid PV, wind and biogas battery system is considered as a reliable source of electricity. To achieve this, a remote location needs to be found [28][33]. NijhumDwip was selected as an isolated rural area for this study. It is located about 4 km south of the mainland in Noakhali district, southeastern Bangladesh. The burden on the study area and the potential of renewable energy sources are evaluated [13][15]. In addition, the marketability of solar, wind, and biogas, as well as the cost of equipment for the system installation, need to be evaluated. The "Renewable Power Hybrid Optimization Model" (HOMER) software tool developed by the National Renewable Energy Laboratory (NREL), Colorado, USA, feeds and analyzes the test data for simulation, optimization, and realization purposes. Using the HOMER micro power optimization model, the design of grid-connected or off-grid hybrid power systems is simplified. Grid independent energy systems have been modeled, simulated, optimized, and analyzed for high sensitivity using HOMER software for various applications. Along with simulation, optimization and sensitivity analysis, profitability analysis is performed to determine financial viability[22][39]. The objectives and scope of the study are taken into consideration while designing the hybrid energy system. Further, the proposed design in HOMER is functionally tested using Electrical Transient Analysis Program (ETAP) and the results of HOMER software are verified using Fuzzy Expert system. The study area, NijhumDwip, has a huge potential for renewable resources like solar, wind and biogas. The design and planning are optimized to achieve the best results. HOMER will then determine which of the proposed architectures the best is [31].

### 2.2.1 Flow Chart of the Methodology

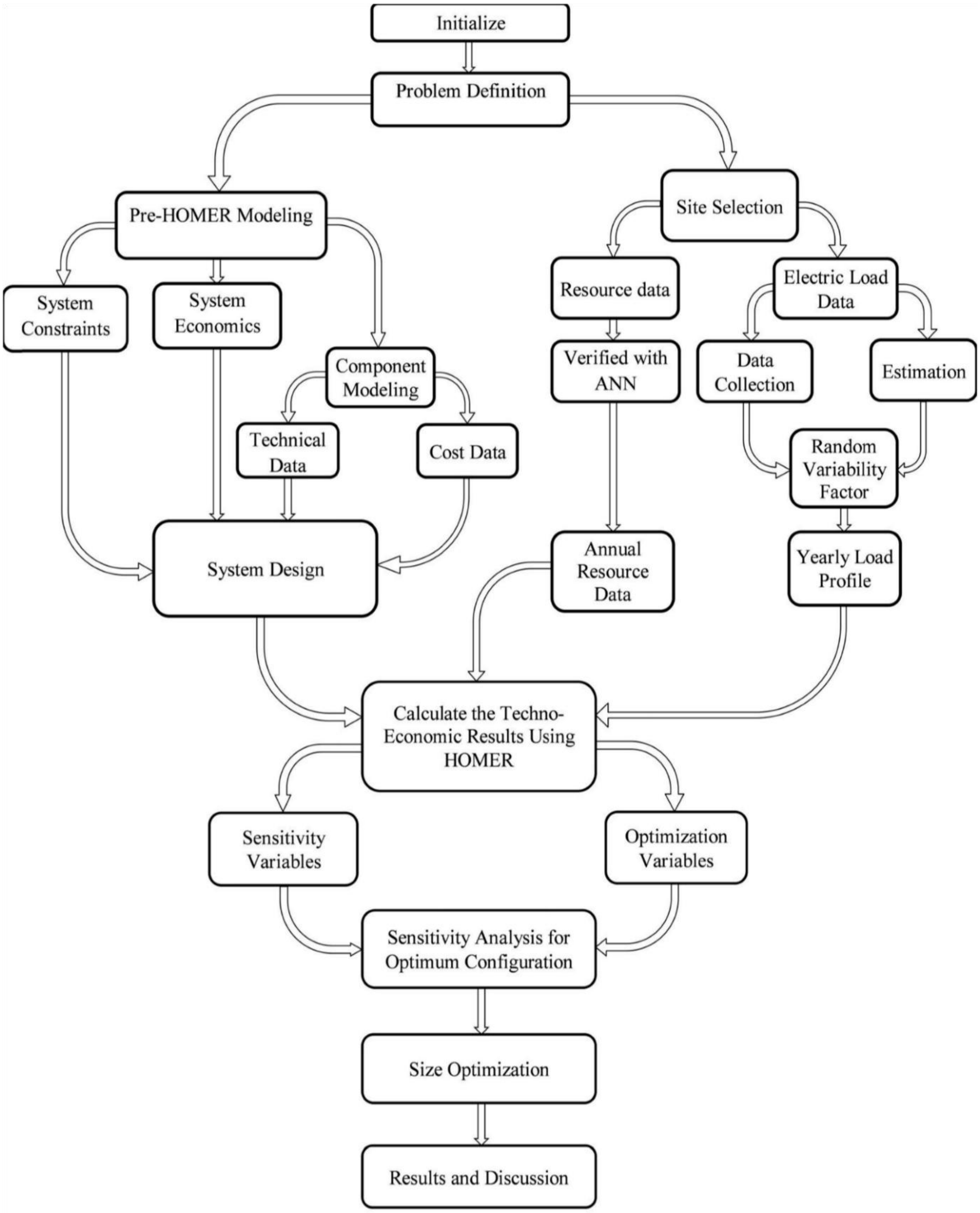



**Figure 2.1:- Flow chart**

### 2.2.2 Boundaries

During the study period, we encountered some limitations and established specific assumptions to refine the document. This research aimed to determine load demand by taking into account the actual capacity factor and the income levels of residents in the study area. To obtain precise data on the electricity needs of the community, it would be beneficial to conduct a survey among the villagers who are in need of electricity [40].Though the current number has been taken into consideration while estimating the actual power load needs of the area, the assumed number of households in this area may be an outdated figure. To get the most accurate cost of the power system components and installation cost, various approaches have been attempted. However, the actual current prices were not available.

### 2.2.3 Site Selection

NijhumDwip is our study area. It is a small Island. It is situation in Noakhali district in Bangladesh. Once it was called Osmanio char and Bhalur char. NijhuDwip a remote off grid Island in Bangladesh, where maximum people deprived in electricity. The national geographical map is located between latitude 22º1´ and 22º6´N and longitude 90º58´ and 91º3´E supply the energy to these areas is difficult, so that expansion of the grid is also not a viable solution. Nijhumdwip's geographical, environmental, and socio-economic features make it an ideal location for off-grid renewable energy systems. The island's access to solar, wind, and tidal energy, coupled with its isolation from the main grid, makes off-grid renewable solutions a practical, sustainable, and resilient choice for the community. These systems not only provide energy but also enhance the island's environmental sustainability and contribute to the local economy.

### 2.2.4 Data Collection for Load Assessment

Dwellings in remote areas are simple and do not require much power for lighting and appliances. In Bangladesh, demand tends to be highest in the evenings, mainly for lighting. In recent years, the demand for electricity has increased with the improvement in socio-economic status of the population. Half of the summer load was considered in winter as ceiling fans are not required. Around 5% of the homes have mixed load requirements. However, while assessing the burden, the initial number of facilities and possibility of additional construction are taken into consideration. Then the planning requirements are considered [26]. While performing the load assessment, winter and summer loads are considered.

### 2.2.5 Resources Assessment

A resource assessment for renewable energy typically examines the potential of various renewable sources, including solar, wind, hydro, biomass, and geothermal energy, within a specific location. This process includes identifying available resources, evaluating their feasibility for energy generation, and analyzing their efficiency and economic viability.NijhumDwip, given its geographical positioning, possesses a rich array of renewable resources, much like the rest of Bangladesh. Thus, it is crucial for this study to gather essential data, such as the monthly average solar radiation and transparency index from NASA's surface weather and solar energy database, as well as average wind flux from the Bangladesh Meteorological Department and SREDA[36][37]. Additionally, data on the number of cattle grazing—pertinent for biogas production—will be sourced from primary observations within the study area.

### 2.2.6 Selection of Parameters

Photovoltaic modules, wind turbines, biogas generators, batteries, power converters are components of the energy system. In the HOMER software, the price, model, number of units used, operating hours, etc. of each of these devices must be specified. The following sections provide the cost and description of these components. Photovoltaic modules (PV), wind turbines, and biogas generators are the three main renewable energy components in the power simulation. A solar-based PV board contains complex parts such as batteries, inverters, and the photovoltaic PV itself. The power generated by photovoltaic modules is direct current (DC), while the power generated by biogas and diesel generators is direct current (DC). Wind turbines are alternating current (AC) [4][5][9]. The inverter changes the current from DC to AC and back again. Electricity from renewable energy sources is used to power consumers. This refers to electricity being generated from other energy sources when sunlight is not available. When sun or wind is insufficient or unavailable, electricity is generated using biogas or diesel.

### 2.2.7 Implementation

The study consists of four comprehensive implementation activities, which include all fieldwork, data management, and reporting. Completion of the equipment and design of the hybrid energy system are both part of the planning phase. Physical data collection from the study area is part of the fieldwork. Compiling of the completed equipment, preparation of formats for data entry, data entry and review, and data analysis are all part of data management. The objectives and scope of the study are considered in the design of the hybrid energy system. After finding a way to collect the data, a tool was developed for the system. Data from the study area was collected after setting the objectives. Information was collected from field questionnaires [22][41]. Additionally, interviews were conducted with key people depending on the situation. The survey data was first entered into the HOMER software for simulation, optimization, and realization. The system is developed using ETAP, using the most suitable HOMER options. ETAP and the Fuzzy Expert system are used to validate the HOMER results. The financial model created as a result of this analysis and insights from the collected data serve as the basis for report creation [32][47].

### 2.3 Conclusion

Evidence of recognizable location was an outstanding outcome with this methodology. This was followed by an assessment of loads and renewable resources. Various market components and their respective costs have been evaluated for the proposed hybrid system. Due to the intermittent nature of solar and wind energy and biogas are used as alternative energy sources. The electricity generated is expected to meet the needs of the study area

# CHAPTER 3

# SYSTEM MODELLING

### 3.1 Introduction

The study area of NijhumDwip is discussed in detail in this chapter. This remote area is unique due to abundant solar radiation, wind speed and biogas resources. The cost and availability of various hybrid components for the hybrid energy system are evaluated. Finally, the system is modeled with the available renewable resources.

### 3.2 Survey Area

Survey of Nijhumdwip, an island located in the Bay of Bengal, would cover several important aspects including geography, population, climate, ecology, and infrastructure.

**Location**: Nijhumdwip is situated in the Bay of Bengal, off the coast of Bangladesh, near the Sundarbans. It lies at approximately 21°30′N latitude and 90°50′E longitude.

**Area**: The Island spans an area of around 40 square kilometers.

**Topography**: The Island is characterized by low-lying land, mangrove forests, tidal rivers, and sandbars. It is part of a deltaic region, with the land being continuously shaped by tidal movements, erosion, and sediment deposition.

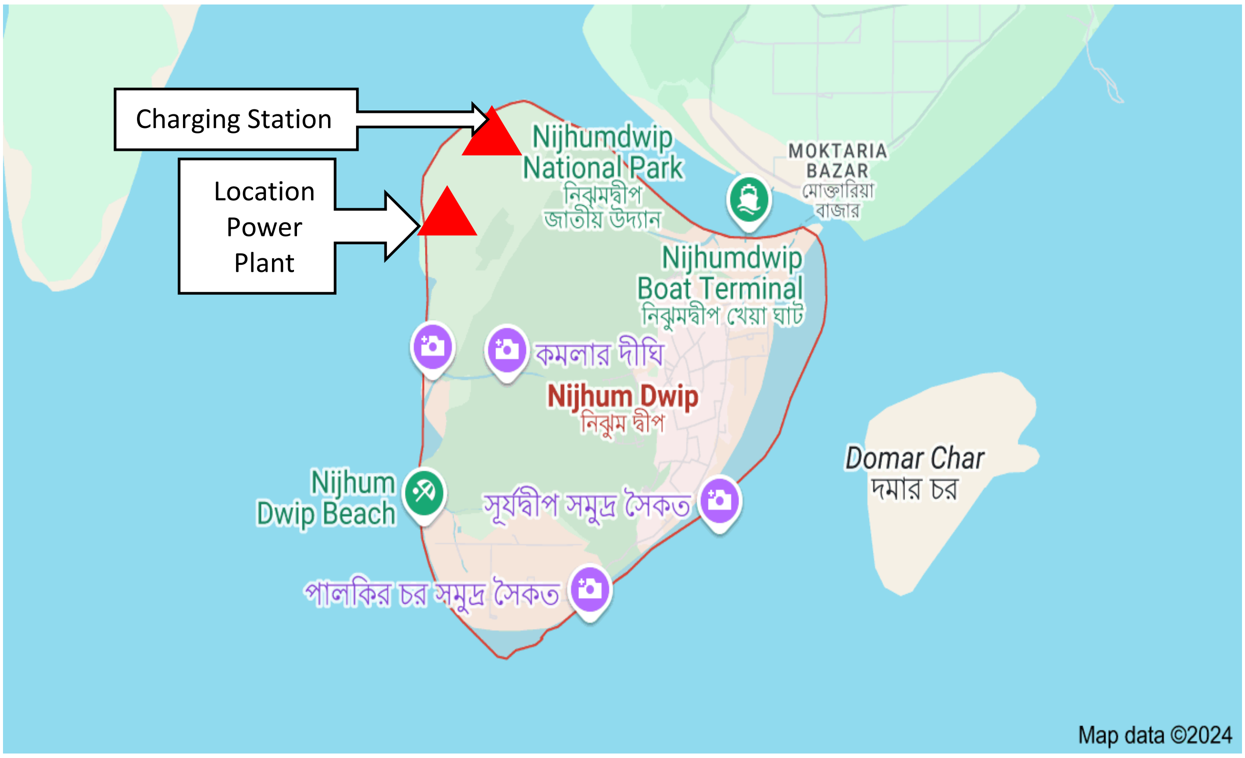



**Figure 3.1:- Survey area map**

NijhumDwip is bordered to the east by Sandweep, to the north by Urir Char, to the south by the Bay of Bengal, and to the west by Noakhali mainland. The island is off-grid and has average maximum and minimum temperatures between 30 and 45 degrees Celsius. Consequently, the offgrid electrification of the island would reap substantial benefits. Fig. The map displays the neigh boring islands along with the survey area. In 1978, NijhumDwip emerged in the Bay of Bengal. Initially recognized as "Island Ruhulamin" in the Noakhali district, it was subsequently renamed "Jahaijjar Island" or "Jahaijjar Char." The island later adopted the name NijhumDwip (Golden Island). Nevertheless, the Bangladesh Armed Forces were entrusted with the task of enhancing governance and security in this coastal region, undertaking afforestation and habitation efforts since 2013.

### 3.2.1 Load Assessment

The load of a survey area can be determined by:

$$E_{Demand} = \sum_{i=1}^{Load} P_{Load} * M_{Load} * N_{Load}$$

Where $P_{Load}$ represents the power rating of connected loads, $M_{Load}$ indicates the duration of operation, and nLoad refers to the count of each connected load [15].

**Electric Load Assessment**

To accurately gauge the residential load in NijhumDwip, we classified households based on lifestyle and estimated the energy load for each category. We also evaluated potential loads in various establishments, including markets, educational institutions, mosques, Union Parishad (U P), healthcare facilities, police stations, and land offices [9].

**Information Gathering**

Our detailed information collection efforts in NijhumDwip have paved the way for effective energy strategies, enhancing our understanding of both residential and institutional energy needs. This solid foundation promotes efficiency, sustainability, and resilience.

**Electricity Load Profile Analysis**

The hourly load profile chart showcases electricity consumption throughout the day, broken down by each hour. It reveals typical electricity usage patterns in the area, identifying peak consumption times and variations between weekdays and weekends. This valuable data enables us to design and optimize energy systems, plan for capacity needs, and accurately predict electricity demand.

**Table 3.1 Daily Load Consumption of Selected area**

| | | | | **Summer Season** | | **Winter Season** | |
|---|---|---|---|---|---|---|---|
| **S.l** | **Load Description** | **Number in Use** | **Power (WATT)** | **Using Per Day/Hour** | **Watt Hour/day** | **Using Per day /Hour** | **Watt Hour /day** |
| 01 | **Religion Institute** | | | | | | |
| | A) CFL Bulb | 4 | 20 | 4 | 320 | 4 | 320 |
| | B) Celling Fan | 3 | 75 | 6 | 1,350 | 0 | 0 |
| | C)Water Pump | 1 | 780 | 2 | 1560 | 2 | 1,560 |
| | Total For One | 1 | 875 | | 3,230 | | 1,880 |
| | **Total Load** | **25** | **21,875** | | **80,750** | | **47,000** |
| 02 | **Small Shop/Tea Stall/Club/pharmacy** | | | | | | |
| | A) CFL Bulb | 2 | 20 | 5 | 200 | 4 | 160 |
| | B)Celling Fan | 1 | 75 | 7 | 525 | 0 | 0 |
| | Total For One | 1 | 95 | | 725 | | 160 |
| | **Total Load** | **170** | **16,150** | | **1,23,250** | | **27,200** |
| | **Household (Poor)** | | | | | | |
| | A) CFL Bulb | 2 | 20 | 5 | 200 | 5 | 200 |
| 03 | B) Celling Fan | 1 | 75 | 10 | 750 | 0 | 0 |
| | Total for One | 1 | 95 | | 950 | | 200 |
| | **Total Load** | **500** | **47,500** | | **4,75,000** | | **1,00,000** |
| | **Household (solvent)** | | | | | | |
| | A) CFL Bulb | 5 | 20 | 6 | 600 | 6 | 600 |
| 04 | B) Celling Fan | 3 | 75 | 14 | 3,150 | 0 | 0 |
| | C) Water Pump | 1 | 780 | 1 | 780 | 1 | 780 |
| | Total For One | 1 | 875 | | 4,530 | | 1,380 |
| | **Total Load** | **200** | **1,75,000** | | **9,06,000** | | **2,76,000** |
| 05 | **House Hold (very solvent)** | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | A) CFL Bulb | 6 | 20 | 6 | 720 | 6 | 720 |
| | B) Celling Fan | 4 | 75 | 15 | 4,500 | 0 | 0 |
| | C) Water Pump | 1 | 780 | 1 | 780 | 1 | 780 |
| | D)Refrigerator | 1 | 250 | 24 | 6000 | 24 | 6,000 |
| | E) LED TV | 1 | 110 | 5 | 550 | 5 | 550 |
| | Total For One | 1 | 1,235 | 10,<br>80<br>0 | 12,550 | | |
| | **Total Load** | **100** | **1,23,5<br>00** | | **12,55,000** | | **8,050** |
| | | | | | | | |
| 06 | A) CFL Bulb | 7 | 20 | 3 | 420 | 2 | 280 |
| | B) Celling Fan | 7 | 75 | 6 | 3,150 | 0 | 0 |
| | C)Water Pump | 1 | 780 | 1 | 780 | 1 | 780 |
| | Total For One | 1 | 875 | | 4,350 | | 1,060 |
| | **Total Load** | **6** | **5,250** | | **26,100** | | |
| 07 | **Secondary School** | | | | | | |
| | A) CFL Bulb | 10 | 20 | 4 | 800 | 4 | 800 |
| | B) Celling Fan | 10 | 75 | 6 | 4,500 | 0 | 0 |
| | C)Water Pump | 1 | 780 | 1 | 780 | 1 | 780 |
| | D) Computer | 4 | 120 | 1 | 480 | 1 | 480 |
| | Total For One | 1 | 995 | | 6,560 | | 2,060 |
| | **Total Load** | **2** | **1,990** | | **13,120** | | **4,120** |
| | **Hospital/ Clinic** | | | | | | |
| | A) CFL Bulb | 10 | 20 | 10 | 2,000 | 10 | 2,000 |
| | B) Celling Fan | 10 | 75 | 14 | 10,500 | 0 | 0 |
| 08 | C) Water Pump | 1 | 780 | 2 | 1,560 | 2 | 1,560 |
| | Total For One | 1 | 875 | | 14,060 | | 3,560 |
| | **Total Load** | **2** | **1,750** | | **28,120** | | **7,120** |
| | **Police Station** | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 09 | A) CFL Bulb | 5 | 20 | 10 | 1,000 | 10 | 1,000 |
| | B) Celling Fan | 5 | 75 | 16 | 6,000 | 0 | 0 |
| | C) Water Pump | 1 | 780 | 2 | 1,560 | 2 | 1,560 |
| | d) Computer | 3 | 120 | 5 | 1,800 | | 1,800 |
| | Total for one | 1 | 995 | | 10,360 | | 4,360 |
| | **Total Load** | **1** | **995** | | **10,360** | | **4,360** |
| 10 | **Commercial (Market)** | | | | | | |
| | A) CFL Bulb | 3 | 20 | 8 | 480 | 8 | 480 |
| | B) Celling Fan | 2 | 75 | 10 | 1,500 | 0 | 0 |
| | Total for one | 1 | 95 | | 1,980 | | 480 |
| | **Total Load** | **40** | **1,425** | | **79,200** | | **19,200** |
| 11 | **Administrative building** | | | | | | |
| | A) CFL Bulb | 3 | 20 | 3 | 180 | 3 | 180 |
| | B) Celling Fan | 3 | 75 | 8 | 1,800 | 0 | 0 |
| | C) Water Pump | 1 | 780 | 1 | 780 | 1 | 780 |
| | D) Refrigerator | 1 | 250 | 24 | 6,000 | 24 | 6,000 |
| | E) Computer | 1 | 120 | 3 | 360 | | 360 |
| | Total For One | 1 | 1,275 | | 9,120 | | 7,320 |
| | **Total Load** | **4** | **4,980** | | **36,480** | | **29,280** |
| 12 | **Mobile Tower** | | | | | | |
| | **Total Load** | | | | | **10,000** | **10,000** |
| 13 | **Battery Run Auto Rickshaw** | | | | | | |
| | Battery Charging | 1 | 1200 | 3 | 1200 | 3 | 1200 |
| | **Total Load** | **60** | **1200** | **3** | **7,200** | **3** | **7,200** |

**Primary Load =** Religion Institute+ Small Shop/Tea Stall/Club/pharmacy+ Household (Poor) + Household (solvent)+ House Hold (very solvent) + Primary school + Secondary School + Hospital/ Clinic + Police Station + Commercial (Market) + Administrative building + Mobile Tower

**Primary Load (Summer season) =** 80,750 + 1,23,250 + 4,75,000 + 9,06,000 + 12,55,000 + 26,100 + 13,120+ 28,120+ 10,360 + 79,200 + 36,480 + 10,000

=3043380 (W/ day)

=3043.38 (KW/day)

**=3.04338 (MW/day)**

**Eco friendly Fishing Boat Design System:-**

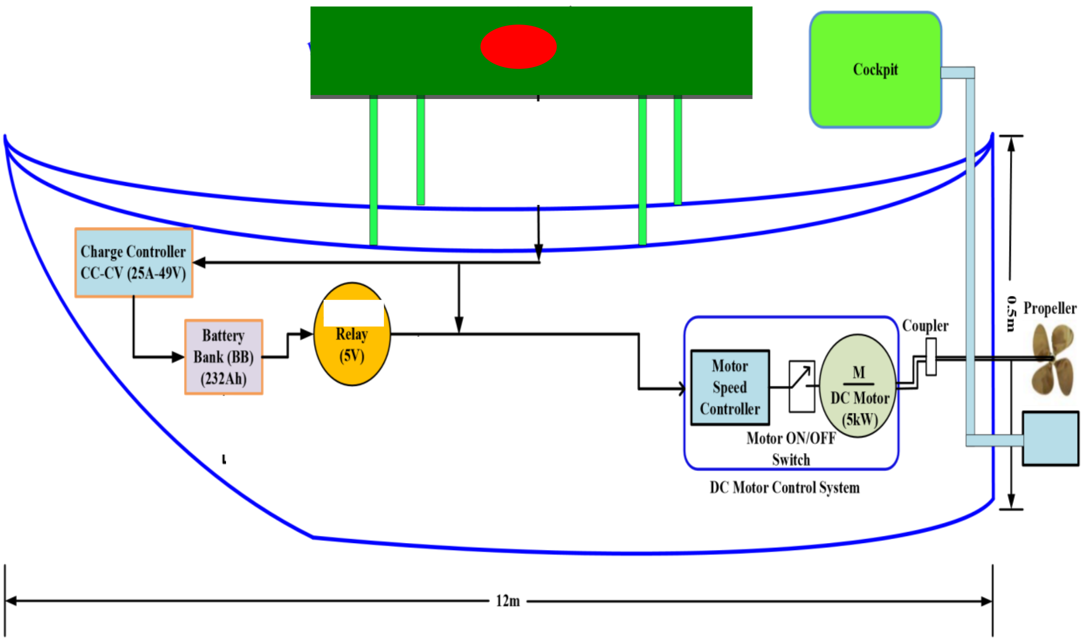



**Figure 3.2:- Eco friendly Fishing Boat Design System**

The gross weight of the boat (full load capacity) = 2400kg

Passenger on board = 8 (70kg per person)

Fishing Net 3 piece = (100*3 kg)

Boat length = 12m (39.37ft)

The displaced volume of water = 2.41m3

Displacement of water by fully loaded boat = 2400kg

Maximum and the safest Hull speed = 15.58 km/hr (8.41knots)

Considered Hull speed = 10km/hr (5.4knots)

Maximum boat speed by propeller and propeller efficiency = 10.06km/hr (5.43knots), 99.43%

Motor Power (horsepower) = Displacement / ($150^2$/ Hull speed$^2$)

Horsepower = 5291/($150^2$/$5.4^2$) = 6.86

Motor Power = 6.86*746 watt = 5.00KW

Daily Load = 25kw (per Boat)

Peak Load = 3.22kw

**Total for 80 Boat 25,000*80=20,00,000 Watt**

**Deferrable Load = Eco friendly Fishing Boat + Battery Run Auto Rickshaw**

**= 20, 00,000+7,200 (w/ day)**= 2007200(w/ day)

=2007.2(kw/ day)

**= 2.007 (mw/ day)**

### 3.2.1.1 Eco Friendly Fishing Boat Charging Station

Boat charging stations are used primarily for electric boats and vessels, offering a sustainable and efficient way to recharge their batteries. Here are some key reasons to use boat charging stations:

**Environmental Benefits**: Electric boats are more eco-friendly compared to traditional fuel-powered ones, reducing greenhouse gas emissions, water pollution, and noise pollution in water bodies.

**Convenience**: Charging stations provide boaters with a reliable and accessible way to recharge their electric boats, especially in areas with a high concentration of boat traffic, like marinas or popular waterfront locations.

**Cost-Effectiveness**: Operating an electric boat can be more economical in the long run compared to fuel-powered boats, as electricity tends to be cheaper than gasoline or diesel.

**Sustainability**: As demand for electric boats grows, charging stations help support the transition to renewable energy sources, especially when combined with solar or wind-powered infrastructure.

**Technological Innovation**: The development of charging stations encourages innovation in the electric boating industry, promoting the growth of electric watercraft options.

**Regulatory Compliance**: In some regions, there are increasing regulations aimed at reducing emissions from boats. Charging stations for electric boats help boat owners comply with these laws.

**Long-Term Investment**: For businesses like marinas or boat rental companies, offering charging stations can attract a growing base of environmentally conscious customers.

**Figure3.3 :- Boat Charging Station**

### 3.2.1.2 Designing a boat charging station

Requires considering both functionality and safety, as it involves water environments and often large-scale electrical systems. Here's an outline of what a well-designed boat charging station could entail:

**1. Location and Docking Setup**

**Docking Bays:** Provide designated docking spaces for boats with compatible charging systems. These should be easily accessible, with floating or fixed docks depending on water levels and the type of boats served.

**Location Considerations:** The charging station should be located in sheltered areas to avoid exposure to rough weather and should be easily accessible from popular boating routes. It may be placed near marinas, harbors, or waterfront areas with high boat traffic.

**2. Power Source and Distribution**

**Renewable Energy Integration:** Biogas, Solar panels and wind turbines can supplement power supply, creating an eco-friendly, sustainable solution. These could be installed on the dock or nearby infrastructure.

**Energy Storage:** Battery storage systems to store excess energy during off-peak times can help balance energy supply and demand.

**3. Charging Infrastructure**

**Universal Plug Compatibility:** Incorporate standard marine charging plugs (such as Type 2 or CCS) along with adapters to accommodate various boat types (e.g., small recreational boats to large yachts).

**Charging Units:** Each docking bay should have its own charging station with clearly marked voltage, amperage, and usage instructions. The stations should be weatherproof and resistant to corrosion due to exposure to saltwater.

**Smart Charging:** Include smart meters and apps to track energy consumption, ensure optimal charging, and alert boat owners when the charging is complete.

**4. Safety Features**

**Waterproof Equipment:** Ensure all electrical equipment and charging interfaces are completely waterproof and corrosion-resistant to meet marine safety standards.

**Grounding and Isolation:** Use isolation transformers to avoid any risk of electric shock, especially in water. Proper grounding systems should be implemented to minimize the risk of electrical accidents.

**Emergency Stop Buttons:** For each dock, include an easily accessible emergency stop button to halt charging in case of a malfunction or emergency situation.

**Overcurrent Protection:** Charging stations should have built-in overcurrent protection to prevent damage to both the boat's electrical system and the charging infrastructure.

**5. User Interface and Monitoring**

**Digital Displays:** Provide clear digital screens that show charging status, estimated time of charge completion, energy used, and billing info.

**Mobile App Integration:** Offer a mobile app that boat owners can use to reserve charging spaces, monitor charging progress, pay for services, and receive alerts when charging is complete.

**6. Sustainability and Environmental Impact**

**Eco-Friendly Materials:** Use recycled or sustainable materials for the physical infrastructure of the station, such as dock materials that reduce the environmental impact.

**Waste Management:** Ensure proper waste disposal systems for any maintenance-related materials, ensuring that waste does not end up in the water.

**7. Maintenance and Accessibility**

**Regular Maintenance:** Schedule routine checks for all electrical and mechanical components to ensure optimal performance. Offer a mobile service or on-site technicians if necessary.

**Accessibility:** Make sure the stations are designed to accommodate all types of boaters, including those with disabilities.

**8. Additional Amenities**

**Rest Areas:** Create relaxing spaces with seating and shading for boat owners while they wait.
**Services Nearby:** Provide nearby facilities like restrooms, cafes, or stores to enhance the overall experience.
**Storage and Charging Lockers:** Offer lockers where boaters can store personal items and secure charging cables.

### 3.2.1.3 Fishing Boat Charging Machines, Charging Control, and Charger Types

The development of electric fishing boats requires reliable charging machines, intelligent charging control, and different charger typesto accommodate various vessel needs. Below is a breakdown of the essential elements of fishing boat charging infrastructure.

**Table 3.2 Types of Fishing Boat Chargers**

| Charger Type | Voltage & Power | Charging Speed | Use Case |
|---|---|---|---|
| AC Slow Charger | 230V - 480V (10-50 kW) | 6-12 hours | Small electric boats, overnight charging |
| DC Fast Charger | 480V - 1500V (50-350 kW) | 1-3 hours | Medium-sized fishing vessels |
| Ultra-Fast DC Charger | 1500V+ (500 kW - 2 MW) | 30 min - 1 hour | Large commercial fishing boats |
| Battery Swapping System | Pre-charged battery packs | Instant | Offshore operations, deep-sea fishing vessels |
| Inductive Wireless Charging | 11-250 kW (emerging tech) | 1-5 hours | Harbors, eco-friendly ferries, fishing fleets |

**A. AC Slow Chargers**

- Best for: Small fishing boats, recreational vessels
- Charging Method: Uses Level 2 AC chargers, typically 22 kW - 50 kW
- Example: Standard marina shore power connections (single-phase or three-phase AC)

**B. DC Fast Chargers (High-Power Marine Chargers)**

- Best for: Medium-sized fishing boats, commercial vessels
- Charging Method: Uses direct current (DC) fast charging with high-voltage connections (480V - 1500V)
- Example:Tritium RTM75, ABB Terra 184 used in Norway's electric ports

**C. Ultra-Fast DC Chargers (Megawatt-Level Charging)**

- Best for: Large fishing trawlers, deep-sea vessels
- Charging Method:
  - Uses 1 MW+ high-power DC charging stations
  - Requires custom-built charging infrastructure in harbors
- Example: Norway's Tromsø Port Ultra-Fast Marine Charging Station

**D. Battery Swapping Systems**

- Best for: Offshore charging, deep-sea fishing fleets
- Method:
  - Fishing boats dock at a station and swap depleted batteries with fully charged ones
  - Reduces downtime since charging is instant
- Example:Eco Marine Power (Japan) developing battery swap tech for fishing boats

**E. Inductive (Wireless) Charging**

- Best for: Harbors, fleet charging, autonomous boats
- Method:
  - Uses electromagnetic induction to transfer energy
  - Works when the boat is docked
- Example:Norway's Plugless Marine Wireless Charger (pilot project)

### 3.2.1.4 Charging Control & Smart Energy Management

**A. Smart Charging Control Systems**

- Optimizes charging speed and grid load
- Prevents battery overheating and overcharging
- Monitors real-time energy usage

- Example: ABB's marine energy management system

**B. Bidirectional Charging (V2G & V2X)**

- Allows fishing boats to supply energy back to the grid
- Helps stabilize port electricity demand
- Example: Norway's V2G (Vehicle-to-Grid) marine trial

**C. AI-Based Charging Load Balancing**

- AI predicts boat energy needs and adjusts charging times
- Reduces peak load stress on power grids
- Example: Siemens Smart Marine Charging Network

**Table 3.3 Specific Charging Machines & Manufacturers**

| **Manufacturer** | **Model** | **Charging Type** |
|---|---|---|
| ABB | Terra HP Marine | DC Ultra-Fast Charger |
| Tritium | RTM75 | DC Fast Charger |
| Siemens | Sicharge D Marine | DC Fast Charger |
| Heliox | Marine DC Fast Charger | DC Fast Charger |
| Cavotec | Automated Mooring + Charging | Inductive & DC |
| Plugless Power | Plugless Marine Wireless | Wireless Inductive |

**3.2.1.5 Detailed Charging Machine Specifications**

**A. ABB Terra HP Marine (Ultra-Fast DC Charger)**

- Type: DC Ultra-Fast Charger
- Power Output: 350 kW - 1 MW
- Voltage: 400V - 1500V DC
- Features:
    - Modular design for high scalability
    - Liquid-cooled charging cables
    - Real-time monitoring via cloud software

**B. Tritium RTM75 (Fast Charger for Medium-Sized Fishing Boats)**

- Type: DC Fast Charger
- Power Output: 75 kW
- Voltage: 480V - 920V DC
- Features:
    - Compact and weather-resistant design
    - CCS2 and CHAdeMO connectors
    - Smart charging control for peak efficiency

**C. Siemens Sicharge D Marine (Flexible Charging Solution)**

- Type: DC Fast Charger
- Power Output: 300 kW - 600 kW
- Voltage: 1500V DC
- Features:
    - Scalable power modules
    - Adaptive power distribution
    - Real-time remote monitoring

**D. Cavotec (Automated Charging + Mooring Systems)**

- Type: Inductive & DC Charging
- Power Output: Up to 1 MW
- Technology: Automated mooring + charging in one system
- Features:
    - Wireless charging for fishing fleets
    - Reduces energy losses with high-efficiency inductive transfer
    - Hands-free connection for safety

**E. Plugless Marine Wireless Charger (Future Tech – Norway Pilot)**

- Type: Inductive Wireless Charging
- Power Output: 250 kW
- Voltage: 800V - 1000V
- Features:
    - No cable connection required
    - High-efficiency electromagnetic energy transfer
    - Works while boats are docked

#### 3.2.1.6 Installation Considerations for Fishing Boat Charging Infrastructure

**A. Shore-Based Charging Station Setup**

- Requirements:
  - High-voltage grid connection (480V - 1500V)
  - Marine-grade DC fast chargers (ABB, Tritium, Siemens)
  - Weatherproof charging cabinets
- Installation Locations:
  - Fishing harbors, commercial docks, marinas

**B. Offshore Floating Charging Hubs**

- Technology: Floating stations powered by solar, wind, or tidal energy
- Example: Norway's offshore Green Floating Charging Hub
- Setup:
  - Battery storage + renewable energy source
  - Wireless charging or robotic battery swapping

**C. Onboard Smart Charging Control Systems**

- Integration with AI and IoT to manage battery charging schedules
- Dynamic load balancing to prevent grid overload
- Remote monitoring & predictive maintenance

**D. Charging Process & Grid Control**

Boat docks at a charging station → charger identifies boat ID and battery level

Grid-controlled EMS analyzes power demand → adjusts charging power based on grid load

Charging starts → optimized for peak/off-peak hours to reduce costs

Renewable sources supply extra power → surplus energy stored in local battery storage

Boat completes charge → session logged in cloud system for analytics

### 3.2.1.7 Daily Load Profile Fishing Boat Charging station

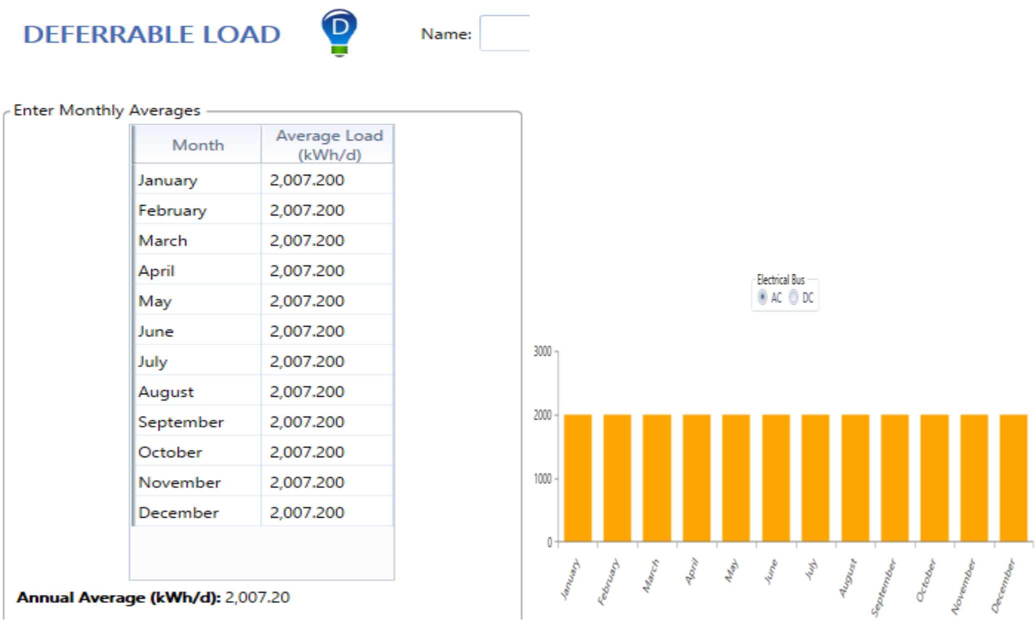
A deferrable load for a charging station in a fishing boat station refers to an electrical load that can be scheduled or shifted to different times without significantly impacting operations. This is particularly useful for optimizing energy costs, reducing peak demand, and integrating renewable energy sources. Shifting charging to off-peak hours when electricity rates are lower reduces operating costs. Many utilities charge extra for high power usage during peak hours. Deferring charging avoids these penalties. Charging multiple boats simultaneously can create high energy demand. Deferring loads helps distribute power usage more evenly. Smart scheduling ensures that boats are charged before they are needed, without unnecessary idle charging.

**Cost Savings**: By shifting charging demand to off-peak hours, charging stations can take advantage of lower electricity rates, reducing operational costs.

**Grid Stability**: Deferable load helps manage overall electricity demand, preventing strain on the power grid during peak hours.

**Energy Efficiency**: It enables more effective use of renewable energy and battery storage, contributing to sustainability.

**Business Growth**: Station owners can enjoy better profit margins, along with potential incentives for load management, making their operations more financially viable.




| Month | Average Load (kWh/d) |
|---|---|
| January | 2,007.200 |
| February | 2,007.200 |
| March | 2,007.200 |
| April | 2,007.200 |
| May | 2,007.200 |
| June | 2,007.200 |
| July | 2,007.200 |
| August | 2,007.200 |
| September | 2,007.200 |
| October | 2,007.200 |
| November | 2,007.200 |
| December | 2,007.200 |

**Figure 3.4:- Daily Load Profile Fishing Boat station**

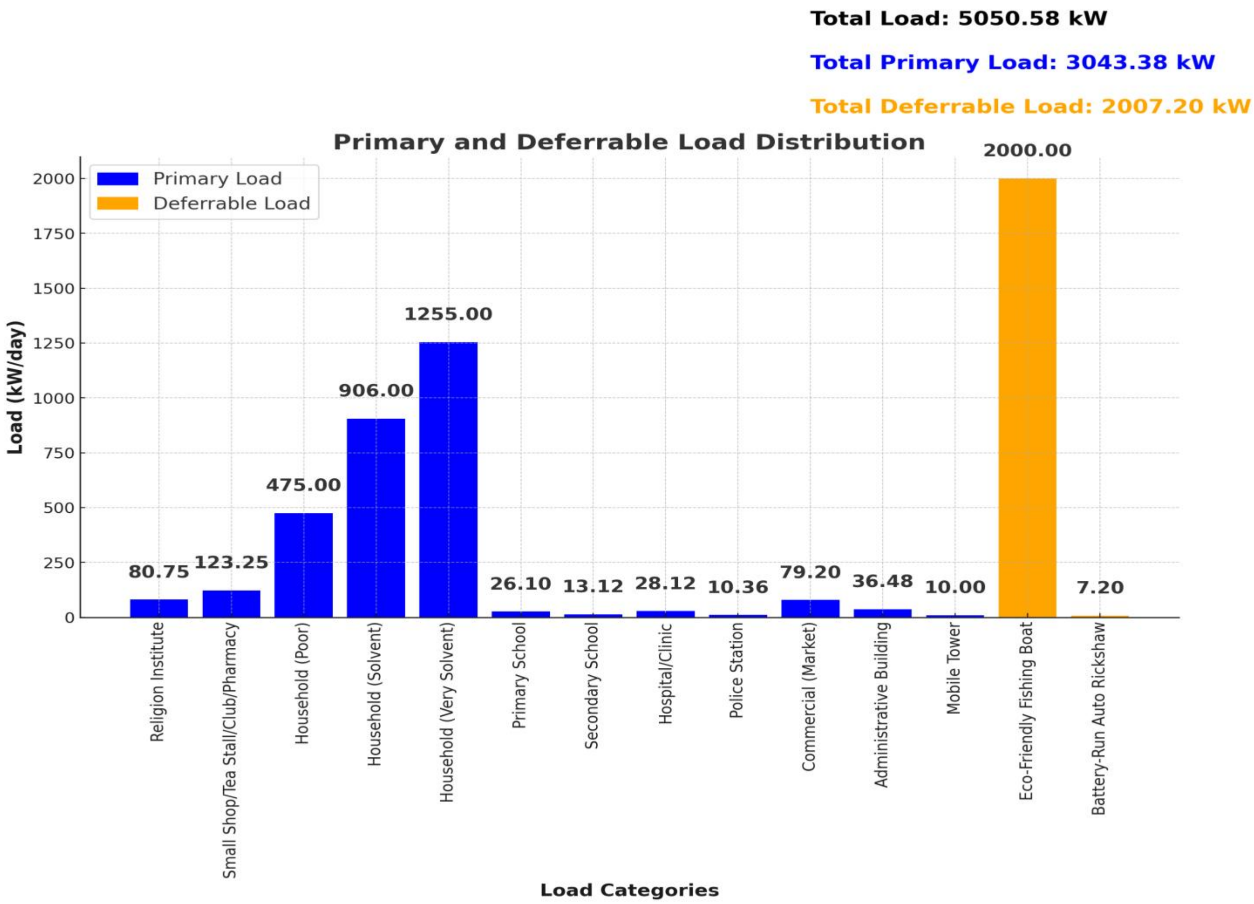
In a charging station, it could be a combination of direct renewable energy and battery storage systems, which ensure that the boats are charged in an environmentally friendly manner. 2007.1 kWh per daymeans the charging station needs to supply a total of 2007.1

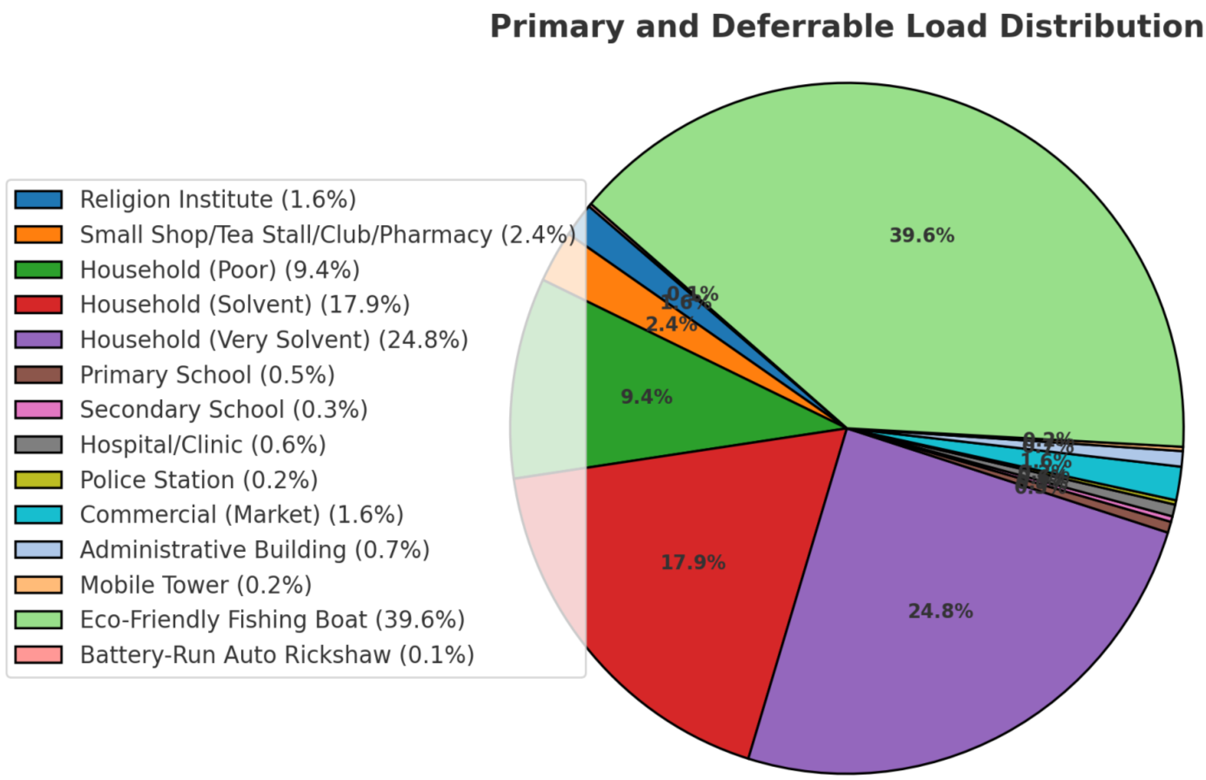
kilowatt-hours of energy every day to charge the boats or other electric-powered vessels. A 2007.1 kWh per day load system is an energy requirement that specifies how much power is needed for charging eco-friendly fishing boats over the course of a day. The system would likely involve a mix of renewable energy generation (solar, wind, biogas), battery storage, and an energy management system to ensure reliable, sustainable operation of the charging station.

By relying on renewable energy sources, the charging station minimizes its carbon footprint, which is critical for ensuring that the fishing boats remain eco-friendly. The boats themselves would be using clean energy instead of traditional fuels like diesel, contributing to lower emissions and a cleaner environment.

### 3.2.2 Estimation of Electrical Load of the Studied Area

In contrast to metropolitan regions, the energy demand in isolated coastal zones is generally minimal, necessitating only a modest quantity of electrical power for household devices. On this island, the primary electrical needs for residential activities consist of lighting, ventilation fans, pho ne chargers, televisions, and refrigerators. Figure 3.5 illustrates the seasonal pattern of NijhumDwip, highlighting that electricity load is comparatively lower during November, December, January, and February.


Total Load: 5050.58 kW
Total Primary Load: 3043.38 kW
Total Deferrable Load: 2007.20 kW
Primary and Deferrable Load Distribution
Primary Load
Deferrable Load
Load (kW/day)
Load Categories
80.75
123.25
475.00
906.00
1255.00
26.10
13.12
28.12
10.36
79.20
36.48
10.00
2000.00
7.20
Religion Institute
Small Shop/Tea Stall/Club/Pharmacy
Household (Poor)
Household (Solvent)
Household (Very Solvent)
Primary School
Secondary School
Hospital/Clinic
Police Station
Commercial (Market)
Administrative Building
Mobile Tower
Eco-Friendly Fishing Boat
Battery-Run Auto Rickshaw


Primary and Deferrable Load Distribution
Religion Institute (1.6%)
Small Shop/Tea Stall/Club/Pharmacy (2.4%)
Household (Poor) (9.4%)
Household (Solvent) (17.9%)
Household (Very Solvent) (24.8%)
Primary School (0.5%)
Secondary School (0.3%)
Hospital/Clinic (0.6%)
Police Station (0.2%)
Commercial (Market) (1.6%)
Administrative Building (0.7%)
Mobile Tower (0.2%)
Eco-Friendly Fishing Boat (39.6%)
Battery-Run Auto Rickshaw (0.1%)
39.6%
24.8%
17.9%
9.4%
2.4%

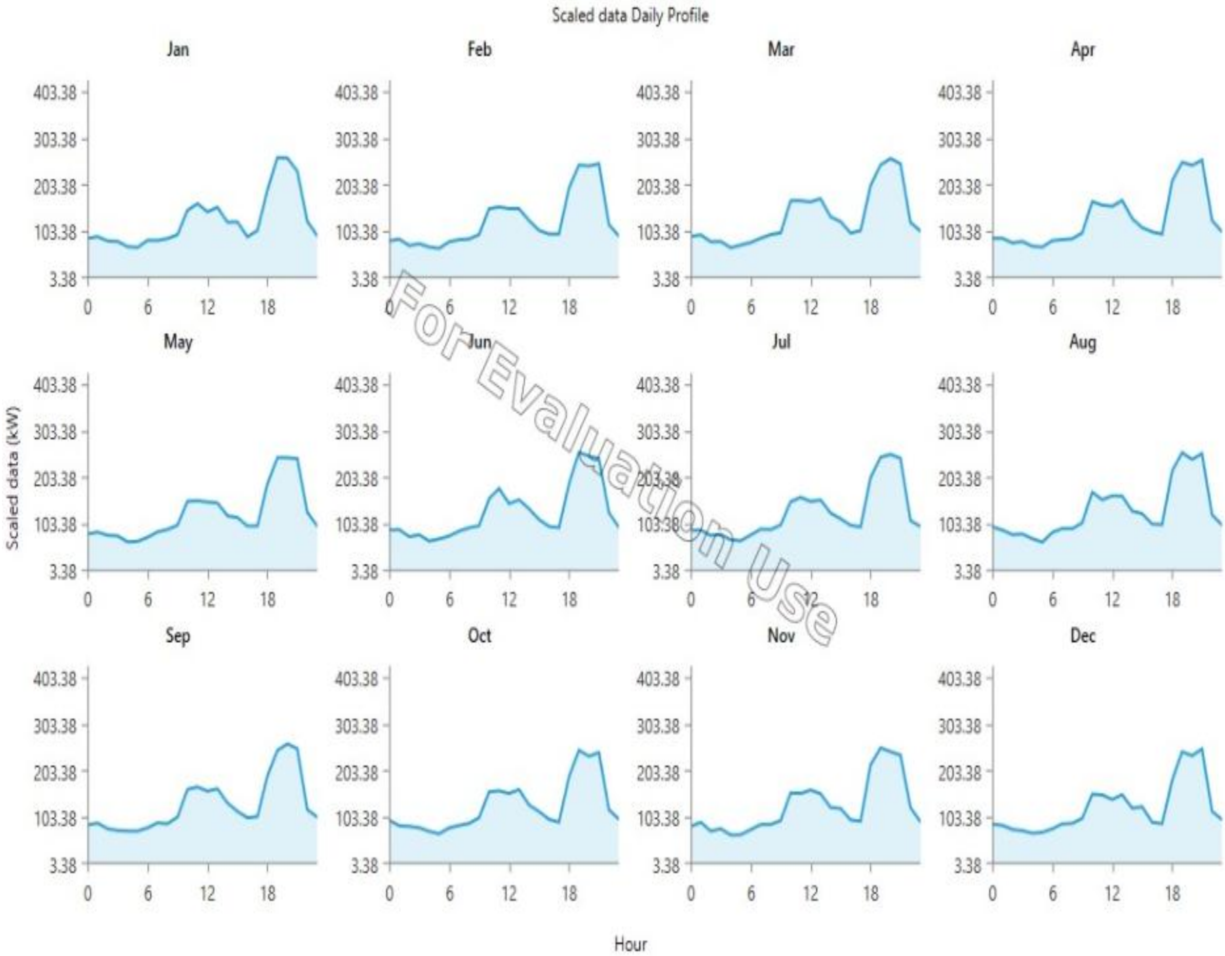




**Figure 3.5:- Seasonal Profile of NijhumDwip**

When solely fundamental electrical devices are in operation, the power usage in the surveyed area hits its lowest at midnight. As individuals prepare for their morning routines, the demand for electricity rises. The load slightly elevates at noon when people gather for lunch and relaxation. The evening hours witness the peak of energy consumption as everyone returns home and activates various entertainment devices.

### 3.3 Renewable Resources at NijhumDwip

#### 3.3.1 Solar Resources and Temperature

Bangladesh, including coastal regions like NijhumDwip, experiences significant solar irradiance due to its tropical climate. The average global horizontal irradiance (GHI) in Bangladesh ranges between 4.5 to 5.5 kWh/m²/day. NijhumDwip, being located close to the equator, is expected to receive relatively high levels of solar radiation throughout the year. Solar radiation tends to be higher in the dry season (November to April), with more cloud cover and reduced irradiance during the monsoon season (May to October). However, even during the monsoon, daily solar radiation can still remain sufficient for small-scale solar applications. The island can expect to receive between 4 to 6 peak sun hours per day on average, which is quite good for solar power generation.

**Table 3.4 monthly solar radiation and Temperature**

| Month | Temperature | Cleanness Index | Daily Radiation (KWh/m$^2$ /d) |
|---|---|---|---|
| January | 20.580 | 0.616 | 4.410 |
| February | 22.870 | 0.604 | 4.979 |
| March | 28.210 | 0.571 | 5.460 |
| April | 27.960 | 0.524 | 5.520 |
| May | 28.800 | 0.465 | 5.130 |
| June | 28.780 | 0.375 | 4.150 |
| July | 28.190 | 0.368 | 4.039 |
| August | 28.090 | 0.394 | 4.190 |
| September | 28.190 | 0.412 | 4.021 |
| October | 27.800 | 0.502 | 4.270 |
| November | 25.330 | 0.577 | 4.260 |
| December | 21.800 | 0.627 | 4.270 |
| **Average** | **26.24** | | **4.56** |

The average temperature on NijhumDwip generally falls between 25°C and 30°C (77°F to 86°F). During the day, it's not uncommon for the mercury to climb above 30°C (86°F), but come nighttime, temperatures tend to cool down to around 22°C to 25°C (72°F to 77°F).


**Figure 3.6:- Monthly Average solar Radiation**

In the winter months, the weather becomes noticeably cooler and drier, with daytime temperatures hovering between 24°C and 28°C (75°F to 82°F) and nighttime lows dipping to 18°C to 22°C (64°F to 72°F). As summer rolls in, the heat intensifies, with daytime highs soaring to 32°C to 36°C (90°F to 97°F), and on particularly hot days, it can even go higher. Nighttime temperatures usually remain above 25°C (77°F). When the monsoon season arrives, the temperatures drop a bit due to regular rainfall and cloud cover. Daytime readings typically range from 28°C to 32°C (82°F to 90°F), while the nights are a tad cooler, resting around 24°C to 27°C (75°F to 81°F).


**Figure 3.7:- Monthly Average Temperature**

The annual average clearness index stands at 0.486. In May, solar radiation reaches its peak 4.56 at kWh/m2, whereas in July, it drops to its lowest at 4.020 kWh/m2. The table above clearly indicates that monthly fluctuations in global solar radiation influence the output performance of PV systems.

### 3.3.2 Wind Resources

A wind renewable energy system for Nijhumdwip could be an effective solution to provide clean, reliable, and sustainable electricity to the island's residents. By harnessing the island's wind resources, off-grid or micro-grid systems could enhance energy independence, reduce reliance on fossil fuels, and contribute to the island's long-term resilience to climate change and environmental challenges. The key steps involve selecting the appropriate turbine technology, assessing wind potential, incorporating energy storage solutions, and ensuring the system is well-integrated into the local community's needs. Coastal areas like Nijhumdwip typically experience moderate to strong winds, particularly during the monsoon season. Wind speeds may range from 4 to 6 m/s (moderate winds) in most areas, which is often suitable for small- to medium-sized wind turbines. Height 25m.

**Table 3.5 monthly wind speed**

| Month | Measured by weather office (25 m) Wind speed (m/s) |
| --- | --- |

| | |
|---|---|
| January | 3.950 |
| February | 4.300 |
| March | 4.700 |
| April | 5.000 |
| May | 5.400 |
| June | 5.900 |
| July | 5.100 |
| August | 4.700 |
| September | 4.300 |
| October | 3.900 |
| November | 3.200 |
| December | 3.000 |
| **Average** | **4.45** |

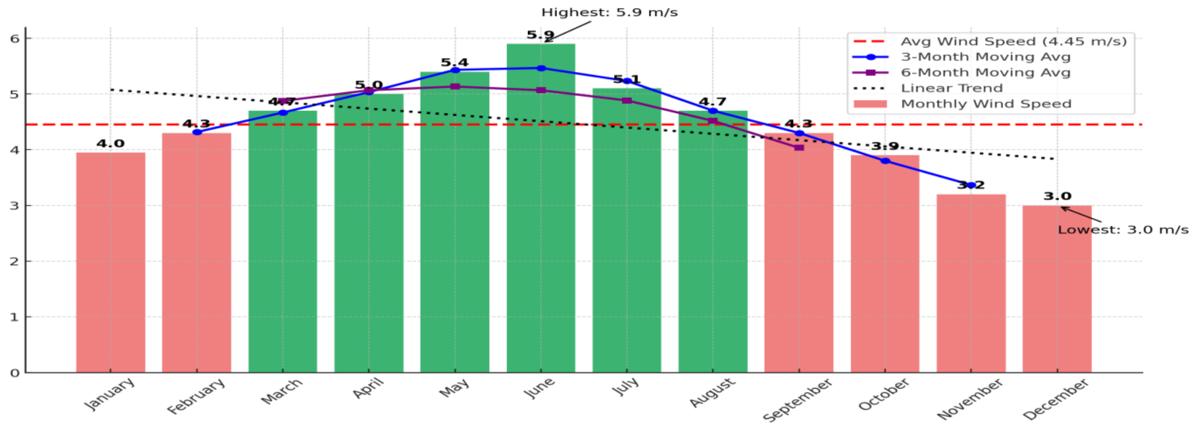



**Figure3.8:- Monthly Average Wind Speed**

The wind velocity required for electricity generation is considerably lower at reduced altitudes. Conversely, when the elevation climbs to 25 meters, the wind velocity is greater in the same region, which possesses significant potential for electricity production.

### 3.3.3 Biogas Resources

On the dairy farms, there are more than 200 buffalo, 300 sheep, and 1,200 hens, ducks, and pig eons. A lower k value signifies that the winds are highly unpredictable, while a higher k value suggests that the winds are stable. The island has a substantial number of grazing livestock, consisting of 4,538 buffalo, 3,335 cows, and roughly 3,255 sheep. A healthy buffalo typically yields around 15 kilograms of manure, while a cow generates 10 kilograms of manure daily and a sheep produces 2 kilograms. [44].

**Table 3.6 month wise cattle dung recovered from Nijhumdwip**

| Month | Tones/Day |
|---|---|
| January | 40 |
| February | 35 |
| March | 35 |
| April | 38 |
| May | 40 |
| June | 35 |
| July | 35 |
| August | 35 |
| September | 35 |
| October | 35 |
| November | 35 |
| December | 35 |
| **Average** | **36.8** |

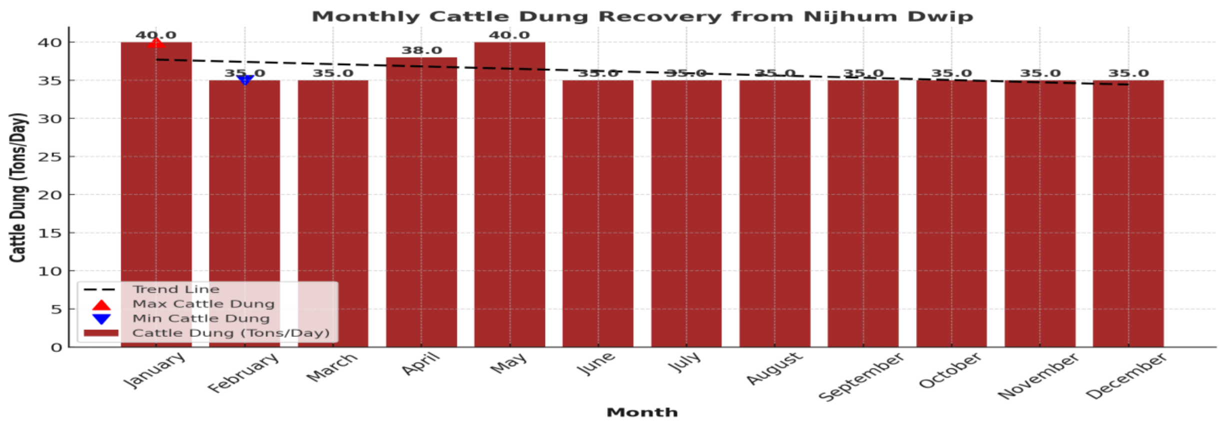



**Figure3.9:-Monthly Average cattle dung recovered from survey area**

Taking into account the 20% recovery efficiency of the dung cake, the island has an estimated availability of approximately 10.786 tons of manure each day. The costs associated with the collection and transportation of manure for the plant area on the island will incur expenses. Nevertheless, marketing the slurry could mitigate the costs related to collection and transportation. Consequently, it can be stated that manure is accessible throughout the year at an average rate of 40. 786 tons per day. The estimation of biogasderived electricity within the survey area is depicted in Table 3.6.

Calculation of amount of electricity produced from dung Total amount of cattle dung cake=10,786 kg

Total amount of biogas production = (10.786 ×0.034) m3 = 366.72 m3

Total production of electricity from Biogas= (366.72÷0.5) kW = 733.44 Kw

I Kg of cattle dung cake produces = 0.034 m3 of biogas

From 0.5 m3 of biogas can generate 1 kW of electricity

## 3.4 Technical Specifications and Cost Assessment

### 3.4.1 System Components Assessment

The hybrid energy system in the study region comprises solar PV panels, a wind turbine, biogas production, a diesel generator, and a power converter. Various metrics, including costs, the necessary quantity of units, operational hours, and more, need to be input into HOMER software for each component.

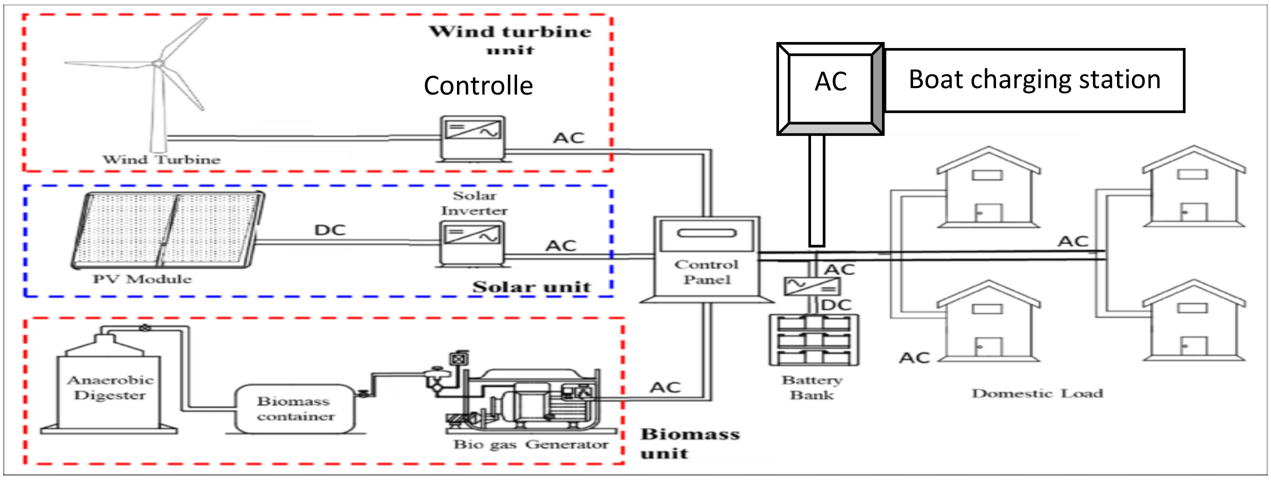



**Figure 3.10:- Architecture of System Components**

Solar photovoltaic (PV) panels, wind turbines, and biogas represent the main renewable energy sources for HOMER. An inverter is utilized to transform the DC output from the solar PV panels to AC, while the wind turbine, biogas generator, and diesel generator also generate AC power. Furthermore, the inverter can change AC back to DC current. The electricity produced by the renewable devices feeds both AC and DC loads. The schematic representation of this system can be found in (Fig. 3.7). Subsequent sections will elaborate on these components.

### 3.4.2 Solar Photovoltaic System

This system could utilize a Longi Solar LR6 PV module. Longi Solar LR6 has been a prominent global developer of solar technologies. It features a lower temperature coefficient, increased output power, and superior low-light performance. The installation cost for solar

PV systems can range from 42Tk to 300 Tk/W. In a favorable scenario, the operation and maintenance (O&M) costs and replacement expenses for a 1W solar energy system are projected to be Tk 54 and Tk 54/W, respectively. Solar PV arrays come with a linear power output guarantee of 25 years, alongside a 12year product warranty, although the y lack a tracking system. The specifics of the PV module are detailed in Table 3.5, while Table 3 .6illustrates the parameters and costs considered for solar PV.

**Table 3.7 SolarPv Module Specification**

| Item | Specification | Unit |
|---|---|---|
| Manufacturer | Longi Solar LR6 | - |
| Module Model | LR6-60PB | - |
| PV Module Type | Flat Plate | - |
| Module Efficiency | 18.7 | - |
| Power Capacity | .305 | KW |
| Weight | 18.2 | kg |
| Cell Type | Monocrystalline PERC | |
| Operating Temperature | -40°C to 85°C | |
| Dimensions | 2024mm x 1002mm x 35mm. | |
| Open-Circuit Voltage (Voc) | 40.2 | V |
| Short-Circuit Current (Isc) | 9.99A | I |
| Rated Voltage (Vmpp) | 33.4 | V |

**Table 3.8 Costs Considered For Solar Photovoltaic System**

| Parameter | Value (BDT) | Value (USD) | Unit |
|---|---|---|---|
| Capital Cost | 1,08,000 | 900 | Per KW |
| Replacement Cost | 84,000 | 700 | Per Kw |
| Operation and Maintenance Cost | 1,200 | 10 | Per kW/YR |
| Lifetime | 25 | 25 | Years |
| Derating Factor | 80 | 80 | Percent |


**Figure 3.11:- Longi Solar LR6 PV module**

### 3.4.3 Wind Turbine

Fluctuations in the wind greatly influence the energy yield from wind turbines. Consequently, the rated capacity of a wind turbine is typically lower than the standard electrical demand. For wind energy, this analysis endorses the AWS 4.2 kW wind turbine. It is a reliable vertical turbine with a low starting wind speed. Employing a three phase outer rotor generator, it starts functioning at a wind speed of 1.5 m/s. It operates both on and off the grid.

| | |
|---|---|
| YAW SYSTEM | Passive by tail Vane |
| YAW / Tower Cable | N x 360° Freedom |
| GENERATOR | PM 3 phase alternator (variable speed ) |
| Insulation Class and Efficiency | Class "H" , > 87% |
| Stator Skew | 1 slot pitch |
| Max stator Core Temperature | 180° C |
| POLES | 16 |
| RPM- 50hz/60hz | 375 / 450 |
| Over speed limit RPM / Hz | 525/70 |
| Monthly KWH 10mph / 4.5 m/s PLF % | 415 kWh (18%) |
| Monthly KWH 12mph / 5.4 m/s PLF (%) | 685 kWh (25%) |
| ROTOR DIAMETER | 4.90m / 16 ft |
| NUMBER OF BLADES | 3 |
| BLADE MATERIAL & Cp | Carbon Fiber composite ~ 0.37 |
| SWEPT AREA | 19 / 205 Sq.m / sq.feet |
| Minimum Tip clearance cm / in | 36 /14 |
| Tip Speed Ratio ( TSR ) | 8.5 |
| LATERAL THRUST ( MAX ) | 4000 nts |
| GOVERNOR / over speed limit | Angle tilt ( Hydraulic assisted ) |
| GOVERN SPEED | 27mph |
| GOV. SHUT-DOWN / OPTIONAL STOP | Electro- dynamic Switch |
| UNIT WEIGHT (tower top ) | 89 Kg. |
| TOWER Top Pipe / Yaw adaptor | P 5" Shd, 40 |
| VOLTAGE options | 48 / 60 - 240 / 380-440 LV / HV / EHV |
| ELECTRONIC CONTROLLER | Incl. but separate |

**Figure 3.12:- AWS 4.2 kW wind turbine**

**Table 3.9 AWS HC 4.2 Wind Turbine Specifications**

| **Parameter** | **Value** | **Unit** |
|---|---|---|
| Rated Power | 4.2 | kW |
| Output Voltage | 220 | V |
| Life time | 20 | Year |
| Maximum Output Power | 4.2 | kW |
| Rotor Diameter | 4.5 | M(ft) |
| Rotor height | 4.5 | M(ft) |
| Startup wind speed | 2.5 | m/s |
| Survival wind speed | 25 | m/s |

| | | |
|---|---|---|
| Rated wind speed | 12 | m/s |

**Table 3.10 Cost Analysis for Wind Turbine**

| Parameter | Value (BDT) | Value(USD) | Unit |
|---|---|---|---|
| Capital Cost | 14,40,000 | 12,000 | Per Turbine |
| Replacement Cost | 12,00,000 | 10,000 | Per turbine |
| Operation and Maintenance Cost | 1,200 | 10 | Per Yr/ Turbine |
| Lifetime | 20 | 20 | Years |

### 3.4.4 Biogas Generator

The cost of biogas plant and biogas generator has been considered together in the hybrid system. For the production of 1kW electricity from biogas, 1200usd is needed including plant cost and generation cost.An installation cost of 10% has also been considered. The Genric Biogas Generator is being considered. Its assessed power output is 50 to 500KW, and it operates as a single phase brush engine. The output voltage is 400 V, with 50 Hz frequency. Details about theGenric biogas generator are found in Table 3.09. The capital cost encompasses s the biogas plant expenses, and Table 3.10 displays this cost.


**Figure 3.13:- Generic Biogas Generator**

**Table 3.11 Specifications forBiogas Generator**

| Parameters | Value | Unit |
|---|---|---|
| Rated Power | 50 to 500 | kW |
| Frequency | 50 | Hz |
| Maximum Output Power | 500 | kW |
| Start-up Time | 5 to 15 min full load | Cc |
| AC Output | 400 | V |
| Gas Consumption | 400 to 450 | m3 /h |

**Table 3.12 Costs Considered For Biogas Generator**

| Parameter | Value (BDT) | Value (USD) | Unit |
|---|---|---|---|
| Capital Cost | 1,44,000 | 1200 | Per kW |
| Replacement Cost | 1,08,000 | 900 | Per kW |
| Continue Working Time | 20,000 | .10 | Operating hour |
| Operation and Maintenance Cost | 12 | 12 | Per hr |

### 3.4.5 Battery Model

Batteries are a crucial investment in small-scale autonomous power systems, as they store electrical energy for use when generation from hybrid PV and wind sources is not available. We have chosen the Hoppecke 12 OPzS battery, which boasts a nominal capacity of 3.59 kWh, a voltage of 2V per unit, and an impressive lifetime throughput of 5080 kWh. The estimated replacement cost is roughly 95% of the original capital expenditure. For detailed specifications, please refer to Table 3.11. The charging of these batteries is expected to occur primarily during daylight hours via the PV arrays, along with additional support from the wind turbine when conditions allow. A comprehensive cost analysis for the battery can be found in Table 3.12.

**Table 3.13 Parametersfor Hoppecke 12Opzs Storage Batteries**

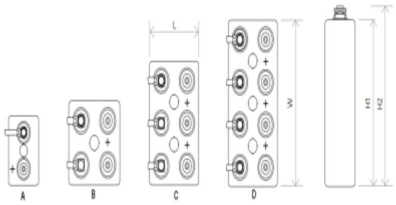
| Parameter | Value | Unit |
|---|---|---|
| Nominal capacity | 3.59 | Ah(kWh) |
| Nominal voltage | 2 | Volt |
| Lifetime throughput | 5080 | KWh |
| Minimum state of charge | 20 | % |
| Round-trip efficiency | 86 | % |

**Table 3.14 Cost Analysis for Battery**

| Parameter | Value (BDT) | Value (USD) | Unit |
|---|---|---|---|
| Capital Cost | 1,44,000 | 1200 | Per Battery |
| Replacement Cost | 1,08,000 | 900 | Per kWh |
| Operation and Maintenance Cost | 60 | .50 | Per /kWh/year |

| Other Specifications @ 20°C | | |
|---|---|---|
| Design Life @ 20°C | 20 | Years |
| Design Life @ 30°C | 10 | Years |
| Design Life @ 40°C | 5 | Years |
| Dimensions (LxWxH1) ± 3 | 210x275x861 | mm |
| Total Height (H2) | 861 | mm |
| Operation temp | -20 to 55 | °C |
| Recommended temp | 10 to 30 | °C |
| Depth of Discharge DOD | up to 80 | % Max. |
| Case / pole settings | ABS / B | A/B/C/D |
| Terminal | M10 | bold |
| Torque setting | 20 ± 1 | Nm |
| Weight ( Dry / Wet ) | 88 / 119 | kg |

Dimensions / Pole settings




Constant Current Discharge - Ampere @ 20°C

| V/Cell | 15 Min | 30 Min | 60 Min | 2h | 3h | 4h | 5h | 6h | 8h | 10h | 20h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,90 | 402 | 393 | 368 | 318 | 262 | 229 | 199 | 179 | 147 | 127 | 80 |
| 1,87 | 513 | 494 | 462 | 365 | 299 | 258 | 226 | 200 | 167 | 142 | 82 |
| 1,83 | 662 | 627 | 552 | 427 | 344 | 289 | 253 | 220 | 183 | 155 | 86 |
| 1,80 | 791 | 743 | 617 | 467 | 370 | 310 | 269 | 233 | 192 | 161 | 91 |
| 1,75 | 949 | 863 | 701 | 511 | 399 | 329 | 284 | 241 | 198 | 166 | 93 |
| 1,70 | 1161 | 1008 | 770 | 541 | 415 | 338 | 292 | 250 | 204 | 167 | 94 |

Constant Power Discharge - Watt @ 20°C

| V/Cell | 15 Min | 30 Min | 60 Min | 2h | 3h | 4h | 5h | 6h | 8h | 10h | 20h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1,90 | 765 | 751 | 705 | 614 | 508 | 445 | 387 | 349 | 286 | 250 | 160 |
| 1,87 | 967 | 933 | 875 | 697 | 573 | 499 | 440 | 388 | 325 | 278 | 160 |
| 1,83 | 1221 | 1163 | 1021 | 802 | 652 | 550 | 483 | 423 | 354 | 299 | 169 |
| 1,80 | 1441 | 1357 | 1136 | 869 | 695 | 584 | 508 | 443 | 369 | 309 | 178 |
| 1,75 | 1691 | 1557 | 1276 | 944 | 742 | 617 | 534 | 454 | 379 | 316 | 182 |
| 1,70 | 2016 | 1795 | 1389 | 995 | 765 | 630 | 549 | 471 | 392 | 317 | 179 |

**Figure 3.14:- Hoppecke 12 OPzS battery**

### 3.4.6 Power Converter

The inverter plays a vital role in transforming power from direct current (DC) to alternating current (AC), as energy generated by solar PV panels is initially in DC form. Our hybrid system effectively integrates both AC and DC networks, making the conversion from DC to AC crucial to ensure a steady energy flow. Details of the chosen inverter specifications can be found in Table 3.13. The cost for installation and replacement is estimated at 1000 BDT/KW for each unit. To ensure a balanced energy flow between the AC and DC components of the power system, a converter is also required. It's important to note that the inverter's rated capacity should be at least equal to or greater than the peak load, as the load will utilize both renewable and nonrenewable sources, even if it operates under conditions lower than the peak. The anticipated replacement cost is projected to be 100% of the initial investment, with the converter demonstrating an efficiency of approximately 90%.

Additionally, the converter is expected to have a lifespan of several years. For a detailed breakdown of costs related to the converter, please refer to Table 3.14.


**Figure 3.15:-Dynapower SPS – 100**

**Table 3.15 Parameters For Power Converter**

| **Parameter** | **Value** | **Unit** |
|---|---|---|
| Rectifier capacity relative to inverter | 100 | % |
| Inverter lifetime | 15 | Year |
| Efficiency | 96.50 | % |
| Rectifier efficiency | 96.50 | % |

**Table 3.16 Cost Analysis for Converter**

| **Parameter** | **Value (BDT)** | **Value (USD)** | **Unit** |
|---|---|---|---|
| Capital Cost | 34,800 | 290 | perkWrated |
| Replacement Cost | 27,000 | 225 | Per kWrated |
| Lifetime | 5 | 5 | Years |

## 3.5 System Modeling

### 3.5.1 Introduction

This paper investigates two distinct types of system modeling. They are

(1) System Component Modeling

(2) Functional Parameter Modeling. The economic model will aid in assessing the feasibility of a proposed design, while the system components will assist in forecasting electricity generation.

### 3.5.2 System Components

Solar PV Modeling When it comes to representing PV panels, there are several methods available. Each panel has two key parameters provided by manufacturers: short-circuit current and open-circuit voltage, which are essential for defining the behavior of PV cells. To effectively model PV systems, it's important to analyze the I-V curve of the panel, which considers three critical components: short-circuit current, open-circuit voltage, and maximum power point [9].Equivalent Electrical Circuit of PV Cell The standard electrical circuit characteristics of a PV cell are depicted in Figure 3.9. The V-I characteristics curve illustrates the relationship between solar-generated current, diode current, shunt resistance, and shunt-leakage current, all of which are linked together both in parallel and in series through the internal resistance that develops during the operation of the system.

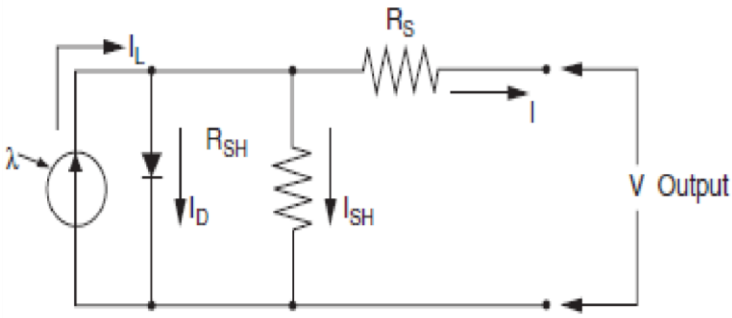



**Figure 3.16:- Equivalent Circuit of Solar PV Cell**

The various elements of the photovoltaic cell represented within the equivalent circuit a re articulated through the following mathematical formulations **[38]**.

$$I = I_L - I_d - Ish$$

Where:

$I_D$: Diode current [A]

I: PV output current [A]

$I_L$: solar generated current [A]

$I_{sh}$: Shunt-leakage current [A]

A slight alteration in the internal resistance developed within the cell can significantly dimini sh the yield efficiency of the PV panel; however, there is no variation in output voltage resulti ng from any modifications to the shunt resistance [38]. Additional mathematical equations ca n be utilized to ascertain the cell's output current, as detailed below.

$$I = D_L - I_o\left[e^{\frac{Q.V_{OC}}{K.T}} - 1\right] - \frac{V_{OC}}{R_{SH}}$$

During actual operation, the final term, which signifies the shunt current, is negligible in com parison to the currents produced by solar energy and the diode, allowing it to be disregarded [

27, 38]. In this type of model, temperature fluctuations within the cell are assumed to be unif orm [39]. The calculations for both open circuit voltage and diode current are determined in t he following manner.

$$V_{oc} = V + I.R_{SH}$$

$$I_D = I_o \left[ e^{\frac{QV_D}{KT}} - 1 \right]$$

Where:

Io: Reveres saturation current of diode [A]

Q: Electron charge [C]

K: Boltzmann's constant [J/k]

$V_D$: Voltage of the diode [V]

T: Cell junction point temperature [°k]

$V_{OC}$: Cell open circuit voltage [V]

In a similar vein, the cell's short circuit current can be calculated by setting the open circuit v oltage to zero, resulting in the short circuit and solar-generated currents maintaining the same magnitude. The diode saturation current (Io) remains constant at a fixed temperature [38], with its mathematical formulation expressed as follows.

$$I_o = \frac{I_{sc}}{e^{Q.Voc} - 1}$$

If the module's short circuit current is available from the cell's datasheet, then at any level of s olar irradiance, the current of the cell can be expressed as follows.

$$I_{sc} = \left(\frac{G}{Go}\right) I_{sc,Go}$$

Where:

Isc: Short circuit current [A]

G: Solar irradiance [$W/m^2$]

Isc,Go: Short circuit current at standard test condition [A]

Go: Solar irradiance at standard test condition [$1000W/m^2$]

The open circuit voltage can be identified by assigning a zero value to the output current.

$$Voc = \frac{AKT}{Q} \log\left(\frac{I_L}{I_o} + 1\right)$$

The effectiveness of a PV cell is assessed through a metric known as the fill factor. This indicates that a high-performing PV system will feature increased levels of short circuit current, open circuit voltage, and fill factor. The fill factor for any solar PV panel hinges on its design and technology. Any factor or malfunction that impacts the fill factor also affects the power yield by lowering the maximum current, maximum voltage, or both simultaneously. The output power of a PV can be computed using the equation as stated in [36].

$$P_{mp} = I_{mp} * V_{mp}$$

$$FF = \frac{V_{OB} * I_{SC}}{P_{mp}}$$

where:

$V_{mp}$: PV maximum potential voltage [V]

$I_{mp}$: PV panels maximum current [V]

$P_{mp}$: PV panels maximum power [V]

FF: Fill factor

Moreover, the output power of the PV can likewise be evaluated by taking into account the influences of solar irradiation and local environmental temperature. The mathematical expressions for the maximum current and maximum voltage

$$Vmp = Vmp.ref * Pv, oc(Tc - Tc, ref)$$

$$Imp = Imp, ref * Isc, ref(Tc - Tc, ref)$$

where:

$V_{mp.ref}$: Potential voltage at standard condition [V]

$P_{V,OC}$: Open circuit temperature coefficient [$V_{ov/k}$]

$I_{mp,ref}$: PV panels maximum current at standard conditions [A]

$I_{SC,ref}$: PV panels short circuit current at standard condition [A]

$T_C$: Cell operational temperature [k]

$T_C$,ref: Cell temperature at standard conditions [k]

A conventional PV module showcasing I-V and P-V Characteristic fig 3.9

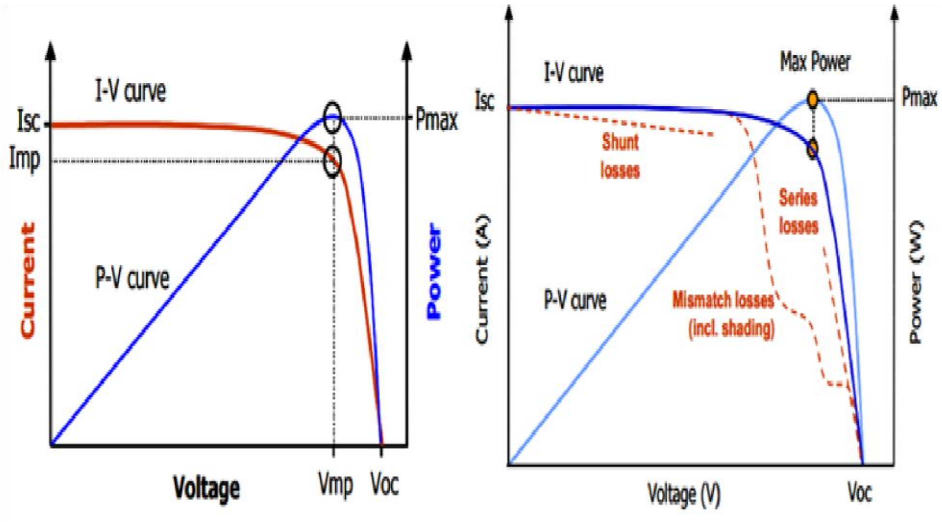



**Figure 3.17: Variation of I-V Characteristic Curve of PV Cell with Categories of Different Losses**

### 3.5.3 Wind Modeling

#### 3.5.3.1 Wind Energy Converters and Regulation Mechanisms

A wind turbine is designed to harness wind energy by converting the movement of air into electricity. When the wind blows, it creates varying forces on the turbine's blades, causing them to pivot and oscillate [15]. This action captures energy from the wind stream. Wind turbines work by extracting kinetic energy from the area that the blades cover, leading to pressure differences along the blades. These pressure changes activate an electrical generator, resulting in electricity production.

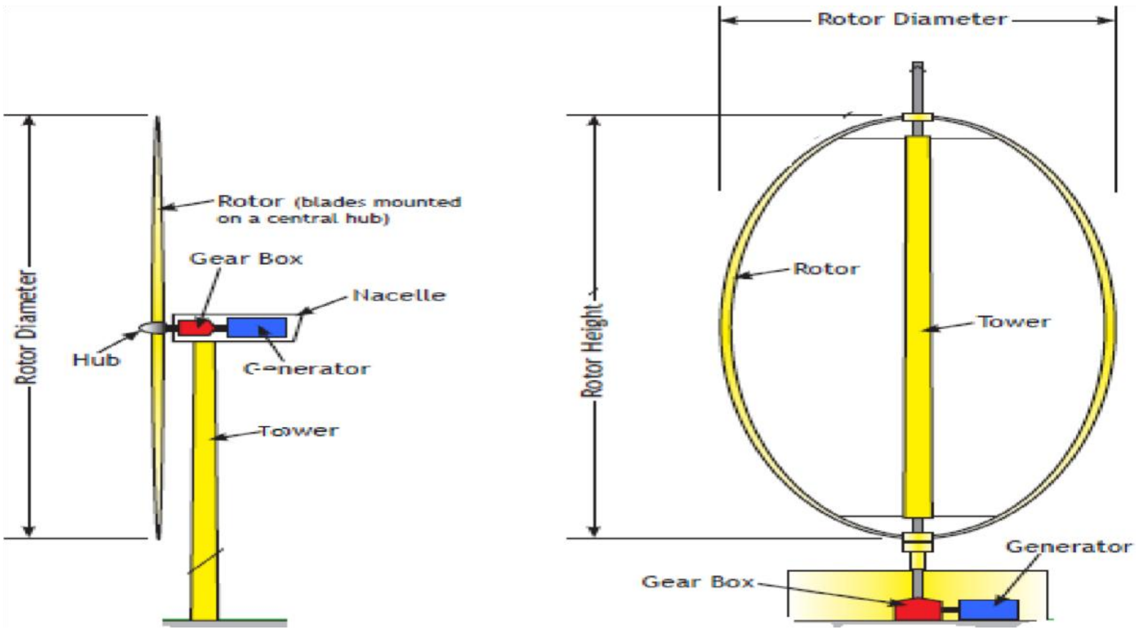



**Figure 3.18:- wind Turbine**

Key components of a wind turbine include the tower, rotor, nacelle, and control systems, such as the yaw mechanism. The tower acts as the structural base, supporting the nacelle, which houses the gearbox and electric generator. The yaw mechanism plays a vital role in ensuring that the turbine rotor is positioned to face the wind, maximizing energy capture. The torque generated by the rotor is transmitted to the gearbox, where it is converted to drive the electrical generator, which in turn transforms mechanical energy into electrical energy. The typical layout of two well-known types of wind turbines is depicted in figure 4-1.

Wind turbines start producing electricity when wind speeds exceed a certain minimum level. As the wind speed increases, the output of the turbine rises until it hits its rated speed, where it delivers maximum power. Once the wind speed goes beyond a designated limit, the turbine stops generating electricity—this is a precautionary measure to ensure safety. There are two essential systems in placeto protect both the turbine and the electrical load during high wind conditions. The first is pitch regulation, which uses an electronic control system to adjust the aerodynamic efficiency of the wind turbine blades. As the wind speed approaches the rated limit, the blades are rotated around their axis to alter their angle. If wind speeds exceed the rated threshold, the system automatically adjusts the pitch of the blades, effectively lowering their performance capability [17]. This rapid response is crucial to keep the turbine operating optimally, allowing it to efficiently convert wind energy when conditions are just right.The second system is stall regulation. Here, the design of the blades is optimized to change their aerodynamic shape without any active adjustment. As the angle of attack increases, air adheres to the upper surface of the blades, creating turbulence that ultimately causes the blades to stall. The unique shape of the rotor blades ensures that as wind speeds rise, this turbulence negatively impacts the turbine's aerodynamic efficiency. Consequently, both power generation and blade speed decline as the wind speed increases, as depicted in the accompanying figure.

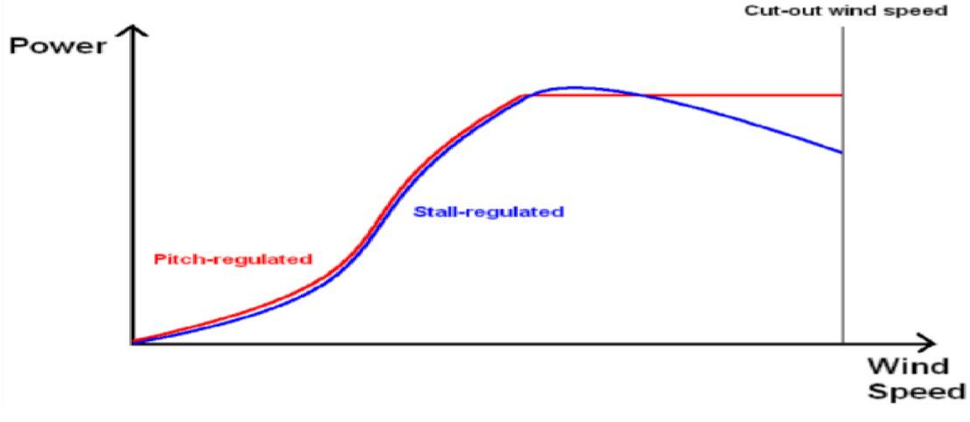


**Figure 3.19:- Wind Turbine Power Control Mechanisms**

The data for the wind turbine is analyzed from a height of 120 meters using the power law as stated in equation (3).

$\frac{U}{U_0} = (\frac{h}{h_0})^{\alpha}$ ………… (1)

Where

U is speed of wind at power level h,

Uo is the speed of wind at level of reference ho, and

α is the surface harshness (is for the most part taken as 0.14).

Moreover, the coefficient of surface roughness, often set at 1/7, is calculated in this assessme nt:

α = [0.37 – 0.088ln($V_0$)]/[1- 0.088ln($\frac{h_0}{10}$)] …….. (2)

where$V_0$and $h_0$are the deliberate speed and level, separately.

The HOMER calculates the power output of the wind turbine as noted in condition (5).

$\frac{\rho}{\rho_0} = (1 - \frac{\beta z}{T_0})^{g/R_\beta}(\frac{T_0}{T_0 - \beta z})$………… (3)

where

ρ is the thickness of air at center level,

ρo is the thickness of air at STP conditions (1.225 kg/m3 ),

$T_o$ is temperature standard (288.16 K),

β is known as slip by rate (0.00650 K/m) and g is speed increase of gravity (9.81 m/s2 ),

R is the gas steady (287 J/kg K) and z is the height (m)

The electrical energy produced by a rotor consisting of at least two cutting edges precisely co nnected to an electrical mechanism is determined from Betz's theorem on power derived from kinetic energy, where three primary factors affect the amount of energy a turbine can harness from the wind: wind velocity, air density, and swept area.

$\rho_a = \frac{1}{2}\rho A V^3 C_p$….(4)

Here, CP represents the capacity factor of the wind turbine, A denotes the swept area of the bl ades, ρ indicates air density, and v signifies wind speed at hub height.

The following equation can be utilized to calculate air density:

$\rho = \frac{P}{RT}$….(5)

where

P is the air pressure (Pa),

R is the gas constant (J=kg=k),

T is the temperature outside (K).

The energy present in the wind varies significantly with the dynamics of wind speed; thus, as suming pairs of wind speeds, there exists considerably more energy in the wind (z3 = 2x2x2 = 8).

Even the slightest fluctuations in wind speed greatly influence the quantity of wind power ava ilable.

### 3.5.4 Biogas Generator

A biogas production system converts organic waste materials into biogas through a process called anaerobic digestion. The system relies on microorganisms to break down organic matter in the absence of oxygen, producing methane ($CH_4$) as the primary component of biogas, along with carbon dioxide ($CO_2$) and trace gases. This biogas can be used as a renewable source of energy for cooking, electricity generation, or heating.

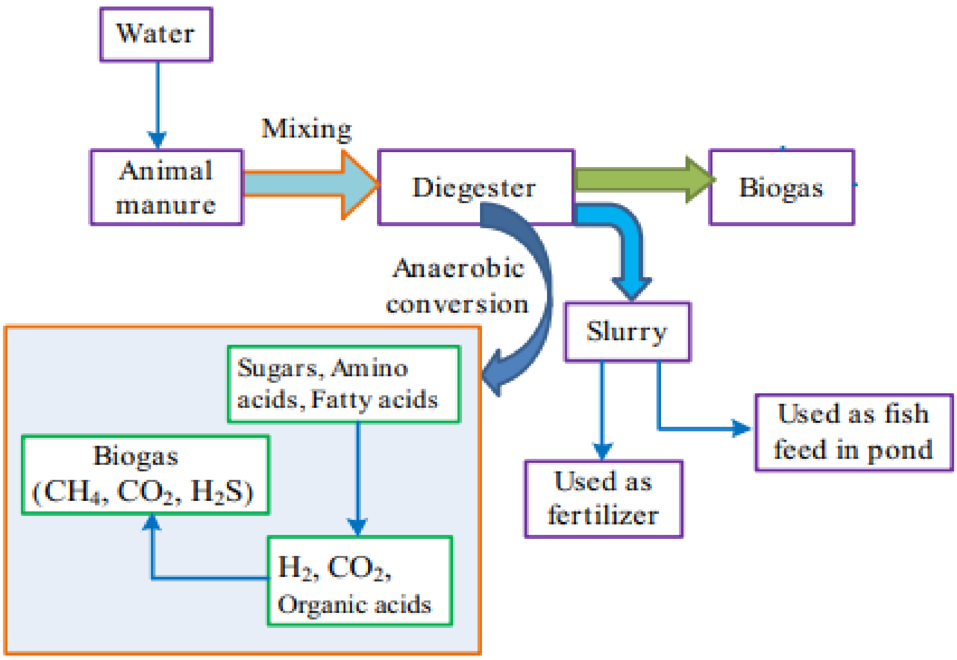



**Figure 3.20:- Biogas Production System**

#### 3.5.4.1 Components of a Biogas Production System

1. **Feedstock**:Organic waste materials serve as the feedstock for biogas production. Common feedstocks include:
   - ❖ **Agricultural waste** (e.g., crop residues, animal manure)

- **Food waste** (e.g., leftover food, kitchen scraps)
- **Municipal solid waste** (e.g., organic household waste)
- **Industrial waste** (e.g., food processing residues, brewery waste)
- **Wastewater sludge**

2. **Anaerobic Digester**:
   - The digester is the core of the biogas production system. It is a sealed, oxygen-free vessel where the organic feedstock is placed for digestion by microorganisms.
   - **Types of digesters**:
   - **Batch digesters**: Organic material is added in batches and left to ferment for a set period.
   - **Continuous digesters**: Organic material is continuously fed into the digester, allowing for constant gas production.
   - **Digester temperature**:
   - **Mesophilic digesters**: Operate at moderate temperatures (30–40°C).
   - **Thermophilic digesters**: Operate at higher temperatures (50–60°C), which can speed up the digestion process.
3. **Microorganisms**:
   - Microorganisms, primarily bacteria, are responsible for breaking down the organic material in the digester. They metabolize the complex organic compounds, producing biogas as a byproduct.
   - **Hydrolytic bacteria** break down large organic molecules into smaller ones [26].
   - **Acetogenic bacteria** convert smaller molecules into volatile fatty acids and hydrogen.
   - **Methanogenic bacteria** produce methane from these smaller molecules.
4. **Biogas**:
   - The biogas produced is typically composed of:
   - **Methane ($CH_4$)**: 50–75%, the combustible part of the gas that can be used for energy.
   - **Carbon dioxide ($CO_2$)**: 25–50%.
   - **Other trace gases**: such as hydrogen sulfide ($H_2S$), ammonia ($NH_3$), and nitrogen ($N_2$).
5. **Gas Storage**:

- After production, the biogas is collected and stored in gas holders or biogas tanks until it is ready for use. The gas storage system ensures that biogas is available for consumption as needed.

6. **Biogas Utilization**:
   - **Cooking**: Biogas can be used as a fuel for cooking, especially in rural areas or regions where cooking gas is scarce.
   - **Electricity Generation**: Biogas can power engines or generators to produce electricity, particularly in off-grid or remote areas.
   - **Heating**: Biogas can also be used in industrial processes or for heating applications.
   - **Upgrading**: The biogas can be purified to remove impurities and increase its methane content, making it suitable for use as natural gas or in vehicles (biomethane).
7. **Digestate (Solid Residue)**:
   - The material left after the anaerobic digestion process is called digestate. It is a nutrient-rich, organic residue that can be used as a natural fertilizer for agricultural fields, improving soil health.

**Components of a Biogas Generator System:**

1. **Biogas Digester (Anaerobic Digester):**
   - The digester is where the organic material is broken down by anaerobic bacteria. The digester is an airtight container where organic waste (manure, food scraps, etc.) is placed, and it is heated and maintained in an anaerobic (oxygen-free) environment to promote microbial breakdown.
   - The output of this process is biogas, which is primarily methane and carbon dioxide.
2. **Biogas Storage:**
   - After being produced in the digester, the biogas rises and is stored in a gas storage system or a gas holder, such as a balloon or pressure tank. The biogas storage allows for continuous gas supply to the generator.
3. **Biogas Purification (Optional):**
   - In some systems, the biogas is purified or cleaned to remove impurities like hydrogen sulfide ($H_2S$), moisture, and other contaminants that could damage

the engine or generator. This step is not always necessary but can enhance the lifespan and efficiency of the system.

4. **Biogas Engine/Generator:**
   - The purified or raw biogas is then directed into an internal combustion engine or gas engine designed specifically for biogas.
   - The engine burns the biogas, which produces heat. This heat energy is converted into mechanical energy that drives the generator.
   - The generator produces electricity by converting the mechanical energy into electrical power.
5. **Power Output:**
   - The electricity generated can be used locally for various purposes like lighting, heating, or powering equipment. In larger setups, the electricity can be fed into the national or local electricity grid.
   - In addition to electricity, the combustion process also generates heat, which can be utilized in various ways, such as for heating water, maintaining the temperature inside the digester, or for industrial heating.
6. **By-Product:**
   - After the digestion process, the remaining material is a digestate, which is rich in nutrients and can be used as an organic fertilizer to improve soil health.

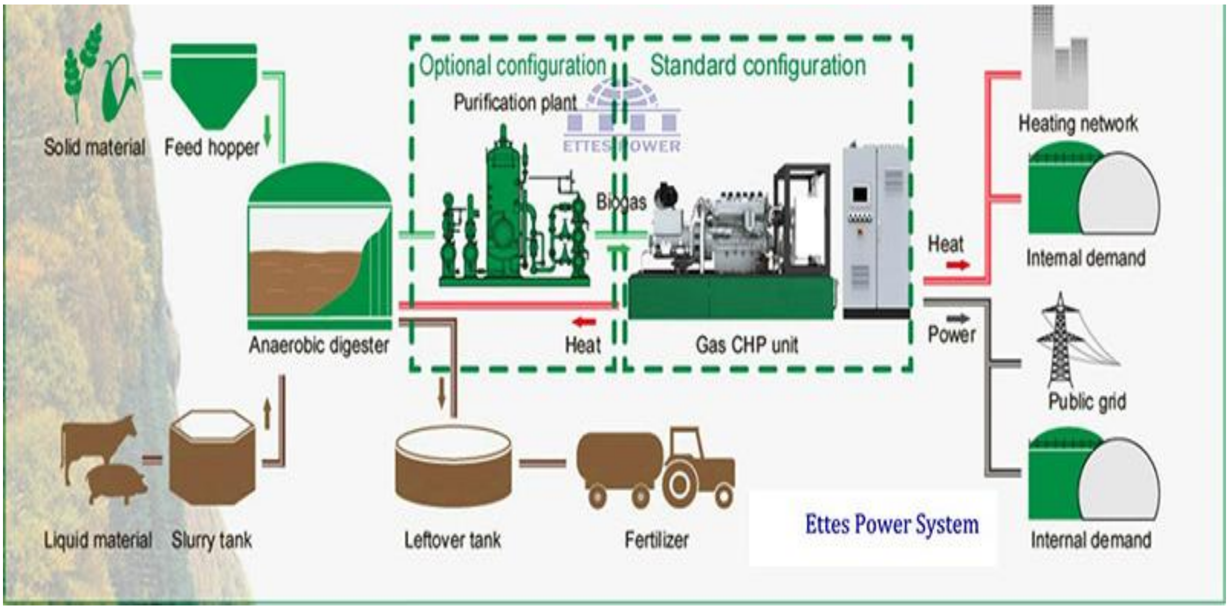


**Figure 3.21:-Biogas Generator**

**Working Principle:**

1. **Anaerobic Digestion:** Organic waste (such as manure or food waste) is placed in an anaerobic digester where it is broken down by bacteria, producing biogas (methane and carbon dioxide).
2. **Gas Collection & Storage:** The biogas rises and is stored in a tank or gas holder.
3. **Purification (Optional):** If needed, the biogas is cleaned of impurities like hydrogen sulfide and moisture.
4. **Biogas Combustion:** The stored and purified biogas is used to fuel an engine in the biogas generator. The engine burns the methane gas, which produces mechanical energy.
5. **Electricity Generation:** The mechanical energy from the engine is converted into electricity by the generator. This electricity can be used on-site or sent to a grid.
6. **Heat Utilization:** The heat generated during combustion can also be used for other purposes, such as heating water or the digester.
7. **Digestate:** The organic matter left after digestion is used as fertilizer.

### 3.5.5 Battery Bank

To ensure the efficient operation of the renewable energy systems and the reliability of the energy supply, the battery bank design will need to be carefully tailored to meet the energy needs of NijhumDwip, considering factors such as daily energy consumption, variability of renewable resources, and peak demand.

**Figure 3.22:- Battery Bank System**

#### 3.5.5.1. Energy Storage Requirements

**Energy Demand Estimation:** The initial phase of calculating the battery bank size involves assessing the total energy consumption of the island. This encompasses residential electricity usage, energy needs of local businesses, and, most crucially, the power demand from charging stations for fishing boats.

**Charging Station Demand:** A key aspect of this evaluation is determining the average energy needed to charge the fishing boats. Factors to consider include the total power required for a full charge of each boat, the number of boats expected to be charged daily, and the anticipated charging duration for each boat.

**Renewable Energy Generation:** The system will be designed to harness energy when production exceeds demand, based on an assessment of available resources like solar, wind, and tidal energy. The battery bank will capture surplus energy during peak generation times (for instance, during sunny or windy days) to ensure a reliable power supply during periods of low generation (such as at night or on calm days).

**3.5.5.2 Battery Bank Sizing Calculation**

Sizing the battery bank entails calculating the necessary energy storage capacity to meet demand during low generation periods. This process considers several factors:

**Autonomy:** The number of days the battery bank can deliver power without requiring a recharge is crucial, especially in areas with significant fluctuations in renewable energy generation.

**Depth of Discharge (DoD):** This refers to the proportion of the battery's capacity that can be safely utilized without causing damage. Generally, a DoD of 50-80% is recommended for most batteries.

**Efficiency:** The effectiveness of the energy conversion and storage processes is another important factor. Batteries usually operate with an efficiency rating of about 80-90%, which should be included in the sizing calculations.

**Type of Battery Technology**

**Lead-Acid Batteries:** Widely recognized for their cost-effectiveness, lead-acid batteries are a popular choice for off-grid energy systems. While they may not pack as much energy into the same space and have a shorter lifespan than other alternatives, their reliability makes them a viable option for remote locations like NijhumDwip.

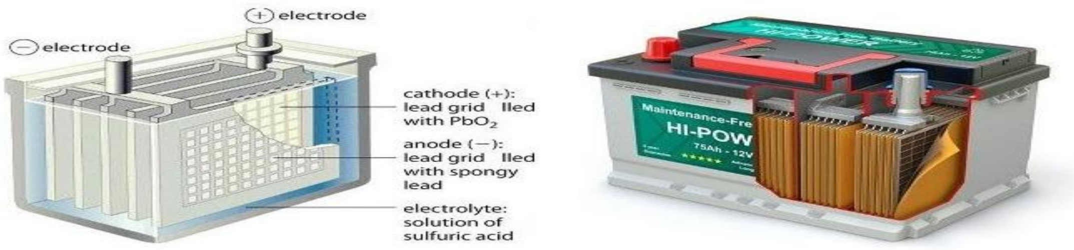



**Figure 3.23:- Lead-Acid Batteries**

**Lithium-Ion Batteries:** These batteries stand out for their superior energy density, extended lifespan, and enhanced efficiency. While they require a larger initial investment, their importance for environmental sustainability and long-term energy goals positions them as a smart option for NijhumDwip, especially at charging stations where efficiency is crucial.


**Figure 3.24:- Lithium-Ion Batteries**

**Flow Batteries:** Known for their scalability and ability to provide prolonged energy storage, flow batteries might be suitable for larger energy systems. However, they are not as commonly used, so it's essential to evaluate their costs and how well they fit the specific needs of the local environment.

### 3.5.5.1 Charging and Discharging of Lead Acid Battery

In a photovoltaic (PV) system, the battery plays a crucial role. During the day, energy generated by solar panels gets stored in the battery, making it available for use when demand arises. During the charging process, the current flows from the PV array or diesel generator into the battery, increasing its terminal voltage and State of Charge (SoC). A charge controller manages this current flow. When discharging, the current moves from the battery to the connected loads, and as the charge level drops, the battery voltage tends to decline quickly. Battery capacity is typically measured in Ampere Hours (Ah), which indicates the amount of energy a battery can hold. Essentially, it's the result of integrating the discharging current in amperes over a specified time. For instance, one Ampere Hour signifies the movement of one ampere over one hour. A battery bank consists of one or more batteries working together. In HOMER, a single battery is depicted as a unit capable of storing a defined amount of direct current (DC) electricity with a particular roundtrip energy efficiency. However, it has limitations in terms of charging and discharging rate, the maximum depth of discharge without damage, and the total energy it can handle before needing replacement. HOMER assumes that a battery's characteristics stay constant throughout its lifespan and remain unaffected by external factors like temperature. Since HOMER believes that lifetime throughput doesn't depend on the depth of charge/discharge cycles, it avoids considering varying depths in different cycles when predicting the lifespan of the battery bank. Instead, it concentrates on estimating the total energy processed by the bank. According to HOMER, the expected lifespan of the battery bank in years can be calculated by:

$R_{batt}$ = min($\frac{N_{batt}Q_{lifetime}}{Q_{thrpt}}$, $R_{batt,f}$) …….(1)

where Nbatt represents the number of batteries in the battery bank, Qlifetime stands for the lif etime throughput of an individual battery, Qthrpt denotes the annual throughput, or the total e nergy processed by the battery bank annually, and Rbatt is the total quantity of batteries prese nt in the bank; f signifies the battery's float life, which represents its maximum lifespan irresp ective of throughput.

HOMER employs the combination of battery wear cost (the expenditure per kilowatt-hour of cycling energy through the battery bank) and battery energy cost (the average expens e of energy stored in the battery bank) to compute its marginal energy cost. The battery wear cost is established by HOMER:

$C_{bw}$ = ($\frac{\text{Crep,batt}}{N_{batt}Q_{lifetime}\sqrt{n}_{rt}}$) ……. (2)

Where,

Crep,batt is the substitution cost of the battery bank (dollars),

$N_{batt}$is the number of batteries in the battery bank,

$Q_{lifetime}$is the lifetime throughput of a single battery (kWh),

andZrt is the full circle effectiveness.

**Charging system**:-illustrates how the terminal potential difference (P.D.) of a cell changes over time during both charging and discharging. As the cell charges, the terminal voltage initially increases from 1.8 V (as shown in the charging curve) to 2.2 V within the first two hours, with a gradual rise following that period. At the end of the charging cycle, the terminal voltage reaches approximately 2.7 V. When the cell is unplugged from the charger, the voltage quickly drops to around 2.2 V without discharging.

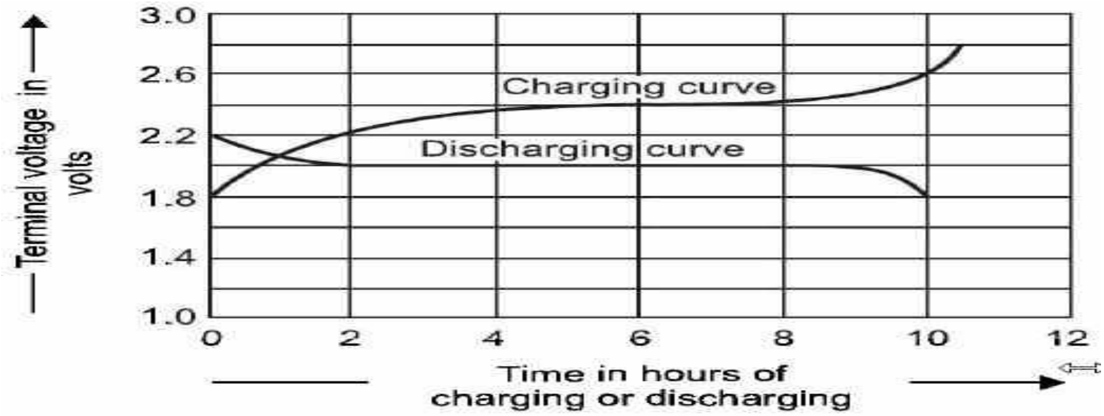



**Figure 3.25:- Charging and Discharging Curve**

During discharge, the terminal voltage starts at 2.0 V, maintains that level for a significant duration, and eventually declines to 1.8 V, at which point recharging is necessary. If the cell discharges below 1.8 V frequently or remains unchanged for a long time, it results in the formation of hard, insoluble lead sulfate (PbSO4) on the cell plates. This greatly increases the internal resistance of the cell and can ultimately damage it.

**Capacity and rate of discharge**. Illustrates how the discharge rate impacts the cell's capacity. As the discharge rate increases, the ampere-hour capacity of the cell tends to decrease. A rapid discharge rate corresponds to a heavier load current, which causes the cell's voltage to drop more quickly due to the heightened voltage loss across its internal resistance. Additionally, this fast discharge weakens the acid within the pores of the plates, leading to more vigorous chemical reactions. Collectively, these factors diminish the cell's capacity.

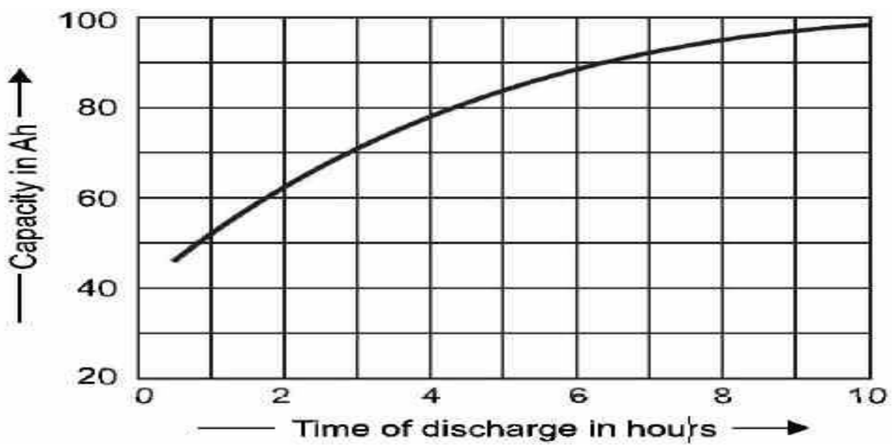



**Figure 3.26:-Capacity and rate of discharge**

The capacity of a cell is typically represented in ampere-hours, based on discharges over 8 or 10 hours. When the discharge rate exceeds this specified limit, the ampere-hour capacity decreases, while a slower discharge rate enhances its capacity.

**Capacity and temperature**. Regarding capacity and temperature, the ampere-hour capacity of a cell tends to rise with increasing temperatures and fall when temperatures decrease. This is because elevated temperatures facilitate greater diffusion of acid and boost the movement of ions involved in the chemical reactions.

### 3.5.6 Charge Controller

A charge controller is essential in Hybrid Renewable Energy Systems (HRES) for effectively managing how energy storage systems, like batteries, are charged from various renewable sources such as solar, wind, or Biogas. Its primary function is to ensure that these batteries are charged safely and efficiently, avoiding issues like overcharging or deep discharging that could harm the battery bank and shorten the overall lifespan of the system.


**Figure 3.27:- Charge controller Hybrid Renewable Energy Systems (HRES)**

#### 3.5.6.1 Key Functions of a Charge Controller in HRES

**1. Voltage Regulation:**The system ensures that the voltage from renewable sources, like solar panels or wind turbines, is appropriately regulated for battery charging.It effectively prevents overcharging by halting the charging process once the battery reaches its maximum voltage capacity.

**2. Current Regulation:**The charge controller is designed to limit the incoming current to the battery, safeguarding it from potential overcurrent that could lead to damage.

**3. Battery State Monitoring:**Continuous monitoring of the battery's state of charge (SOC) and state of health (SOH) helps optimize charging durations and avoid over-discharge, which can significantly reduce battery lifespan.Advanced charge controllers may provide real-time information about battery health, voltage levels, and current.

**4. Overvoltage/Under voltage Protection:**In the event of an overvoltage scenario, the system automatically disconnects the charging source to protect the battery from damage.It also features under voltage protection by disconnecting the load if the voltage falls below a safe threshold, thereby preventing deep discharge.

**5. Load Management:**Charge controllers in Hybrid Renewable Energy Systems (HRES) often come equipped with load management capabilities. This feature enables the system to regulate when and how different loads receive power, ensuring that critical loads are prioritized during times of low power generation.

**6. Energy Distribution:**In hybrid systems that utilize various energy sources—such as solar, wind, and diesel generators—the charge controller plays a key role in managing and prioritizing the flow of energy from these sources. This process ensures that the battery is charged as efficiently as possible. Additionally, the controller can switch between power sources based on their availability and the current battery status.

**7. Maximum Power Point Tracking (MPPT)**: A standout feature of many modern charge controllers, especially those associated with solar energy systems, is the implementation of MPPT technology. This technology optimizes the extraction of power from renewable sources by adjusting the operating voltage to align with the panel's maximum power point, thereby enhancing overall system efficiency.

**8. Temperature Compensation:**Battery charging can be significantly affected by temperature. To mitigate potential issues, some charge controllers automatically modify charging voltages in response to the ambient temperature. This adjustment helps prevent battery damage due to overcharging in high-temperature conditions and undercharging in colder environments.

### 3.5.7.2 Types of Charge Controllers for HRES

**1. PWM (Pulse Width Modulation) Controllers:** These controllers offer a straightforward and budget-friendly solution by managing how long the battery stays connected to the renewable energy source. While they come at a lower cost, they do have lower efficiency compared to MPPT controllers and can lead to some energy loss during the charging process.


**Figure 3.28:- PWM (Pulse Width Modulation) Controllers**

**2. MPPT (Maximum Power Point Tracking) Controllers:**Designed for enhanced efficiency, MPPT controllers are particularly effective in solar applications. They work by optimizing the power extracted from solar panels, adjusting the input voltage to reach the best power point. This can boost charging efficiency by as much as 30%, especially in less-than-ideal lighting conditions.


**Figure 3.29:-MPPT (Maximum Power Point Tracking) Controllers**

### 3.5.7 Load Side Inverter

A load-side inverter in a Hybrid Renewable Energy System (HRES) plays a crucial role in efficiently managing and transforming the DC power generated by renewable resources such as solar panels and wind turbines into usable AC power for homes or businesses. It is strategically positioned on the load side of the system, usually situated between the energy storage unit (like batteries) and the end-users (such as appliances or machinery) in both off-grid and hybrid grid-connected energy setups.

### 3.5.7.1 Key Functions of a Load-Side Inverter in HRES

**1. DC to AC Conversion:**Renewable energy sources such as solar panels and wind turbines produce DC power, which must be converted into AC power for compatibility with most household and industrial devices, like refrigerators, lights, and air conditioners.The load-side inverter plays a key role in this process, efficiently transforming the DC voltage from a battery bank or renewable energy system into standard AC voltage, typically 120V, 230V, or 240V, which is suitable for both home appliances and industrial machinery.

**2. Power Quality Improvement:** The inverter guarantees stable AC power output, maintaining consistent voltage and frequency, which is essential for the reliable operation of electrical equipment. Additionally, through power factor correction, it adjusts the system's power factor, ensuring that energy delivery to loads is as efficient as possible.

**3.Maximum Power Point Tracking (MPPT) Integration:** Many load-side inverters incorporate MPPT technology, especially in solar PV systems, to maximize energy extraction from solar panels. This technology tracks the maximum power point of the solar array and fine-tunes the operating conditions to ensure that the panels generate the highest power output at any given moment.

**4. Battery Charging and Discharging Control**: In a hybrid system, the inverter is responsible for managing the flow of energy between the battery bank and the load. It ensures that excess power from the renewable sources or the grid can be used to charge the batteries efficiently, while power can be drawn from the batteries to supply the load during times of low generation.

**5.Energy Flow Management**: The inverter manages the distribution of energy between various components in the system, such as renewable energy generation (solar, wind), battery storage, and AC loads. It ensures that the energy is distributed efficiently based on demand and supply.

**6. Load Protection and Safety Features:** This inverter safeguards your connected devices against power surges, spikes, and system faults, protecting your sensitive appliances and equipment from potential damage.Key safety features include overvoltage, under voltage, overcurrent, and short-circuit protection, all designed to ensure the system runs safely and efficiently.

### 3.5.8 DC-DC Converter

A DC to DCconverter in a Hybrid Renewable Energy System (HRES) is an essential power electronic device that converts DC voltage from one level to another. These converters are critical in HRES because renewable energy sources like solar panels, wind turbines, and batteries often operate at varying DC voltages. The DC to DC converter adjusts these voltages to ensure that the power is usable and optimized for different components in the system, such as energy storage (batteries) or loads, and helps manage the energy flow between renewable sources, storage, and loads.

#### 3.5.8.1 Key Functions of a DC to DC Converter in HRES

**Voltage Regulation:** A crucial role of a DC to DC converter is to adapt the DC voltage sourced from renewable energy systems (like solar or wind) to the specific requirements for battery charging or powering various loads. For instance, solar panels may output a voltage that isn't ideal for battery charging; thus, a DC to DC converter fine-tunes the voltage to align with the battery's needs.

**Battery Charging Optimization:** In hybrid renewable energy setups, batteries serve as essential energy storage units. A DC to DC converter carefully regulates the charging voltage and current, ensuring that batteries are charged in a safe and effective manner, which helps to prevent any risk of overcharging or undercharging. It can also adjust the voltage levels up or down to meet the charging requirements, particularly when the input voltage from the renewable source experiences fluctuations.

**Improving System Efficiency:**DC to DC converters facilitate efficient energy transfer among the various components of the system. By aligning the voltage levels of power sources, storage units, and loads, these converters help minimize energy loss and enhance overall system performance.

**Maximizing Power Extraction from Renewable Sources:**In solar energy systems, a DC to DC converter plays a pivotal role in implementing Maximum Power Point Tracking (MPPT). It adjusts the voltage and current to ensure the solar panels can operate at their optimal power point, thereby maximizing the overall efficiency of the system.

**Power Flow Control:** DC to DC converters play a critical role in managing power flow within hybrid systems. They effectively regulate how much energy is transferred from renewable sources, the grid, or batteries, ensuring that power reaches its intended destination where it's most needed—be it for charging batteries or supplying loads.

**Protection and Safety:**These converters also include vital safety features such as overcurrent and overvoltage protection, as well as thermal shutdown capabilities. This safeguards the system from potential damage and guarantees reliable operation.

### 3.5.8.2 Types of DC to DC Converters

**Buck Converter (Step-Down Converter):** A buck converter lowers the DC voltage from a higher level to a lower one. In hybrid renewable energy systems (HRES), this is particularly useful when the renewable energy source, like solar panels, provides a higher voltage than what the battery or load requires. For example, if a solar panel outputs 24V DC while a battery needs just 12V DC, the buck converter is employed to reduce the voltage to the desired level.

**Boost Converter (Step-Up Converter):**In contrast, a boost converter increases the DC voltage from a lower level to a higher one. This is essential when the voltage sourced from renewable options, such as wind turbines or solar panels, is insufficient for charging batteries or powering loads. Take, for example, a wind turbine that generates 12V—if the battery demands 24V, the boost converter steps up the voltage to satisfy the requirement.

**Buck-Boost Converter:**The buck-boost converter is a flexible option that can either step up or step down the input voltage, adapting to the specific demands of the system. This versatility allows it to meet varying operational needs effectively.

### 3.5.8.3 Importance in Fluctuating Input Voltage Systems

DC to DC converters are essential for systems where input voltage varies above and below the required level. This is often seen in setups powered by variable sources like wind or inconsistent solar energy. They play a critical role in hybrid systems to keep voltage within the optimal range for charging batteries.

**Cuk Converter:**The Cuk converter functions as a versatile DC to DC converter capable of stepping up or stepping down voltage, much like the buck-boost converter. It provides smooth, continuous current at both input and output, which is beneficial where low current ripple is a priority.

**Isolated DC to DC Converters:**Some hybrid systems utilize isolated DC to DC converters that ensure electrical separation between the input and output. This isolation is crucial for safety, especially in high-voltage applications.They are frequently found in industrial or commercial renewable energy setups that involve multiple DC sources.

**Role in Hybrid Renewable Energy Systems (HRES):**Integrating Renewable Energy Sources: Renewable energy systems like solar and wind generate varying voltage levels, influenced by factors such as sunlight and wind speed. DC to DC converters align these voltage levels with the battery or load requirements, facilitating seamless integration into the overall system.

**Battery Energy Storage**: In Hybrid Renewable Energy Systems (HRES), battery energy storage plays a vital role in balancing the supply and demand of energy. A DC to DC converter is essential for ensuring that batteries charge correctly by converting energy from renewable sources to a voltage level suitable for the battery. Additionally, when it's time to discharge, this converter aids in regulating voltage to provide power to various loads.

**Energy Flow Regulation in Off-Grid and Hybrid Systems:**DC to DC converters are crucial for managing energy flow in off-grid and hybrid systems. They facilitate seamless power distribution among different components, such as solar panels, wind turbines, batteries, and loads. This technology ensures that renewable sources can efficiently charge the batteries while maintaining appropriate voltage levels for every individual component.

**Improved Efficiency and Longevity:** By optimizing voltage levels during charging, DC to DC converters enhance system efficiency and prolong battery life, which ultimately decreases the frequency of replacements and reduces operational costs.

### 3.5.9 Economic Modelling

#### 3.5.9.1 Total Net Present Cost

The equation below is employed by HOMER to calculate the overall net present cost [55]

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i,R_{proj})}; \;\ldots\ldots\; (1)$$

The total annual expense in USD, denoted as C_(ann,tot), is influenced by the annual real interest rate, represented by $'i'$ in percentage terms (this is also referred to as the discount rate). The lifespan of the project is indicated by R_proj in years, while the capital recovery factor is expressed as $(i, N)$, which can be calculated using the following formula:

$CRF(i,N) = \frac{i(1+i)^N}{i(1+i)^{N}-1}$; …… (2)

Where $'i'$ indicates the yearly real interest and $'N'$ refers to the number of years.

### 3.5.9.2 Cost of Energy (COE)

This relates to the average cost per KWh of electricity generated by the system. HOMER employs the ensuing equation to assess the levelized cost of energy [55]:

COE = $\frac{C_{ann,tot}}{E_{prim}+E_{def}+E_{grid,sales}}$; …… (1)

Where C_(ann,tot) represents the total annualized cost, E_prim and E_def indicate the yearly volumes of primary and deferrable loads handled by the system, respectively. Additionally, E_(grid,sales) refers to the annual energy sold to the grid. In this analysis, the E_(grid,sales) value is zero because the systems being evaluated are not connected to the grid and are not designed for future connection. It's important to note that the cost of energy here reflects the average price per KWh of useful electrical output generated by the system, rather than the energy consumed by end-users.

### 3.5.9.3 Pay Back Period

Any project selection process must consider a payback period. This duration signifies the time after which the total project expense will be recouped through the inflows generated by the project. It indicates that the initiative will become profitable following this timeframe.

PBP = $\frac{C_{Cap.}+C_{O\&M}+C_{Repl.}}{C_{Cashinflo}}$

Where C_(Cap.), C_(O&M), C_(Repl.), and C_Cashinflo reflect the capital cost, operational and maintenance expense, replacement cost, and annual cash inflow, respectively. For a project to be feasible and lucrative, it should perpetually remain below T, or the project's duration.

### 3.5.10 Clearness Index

The clearness index is a dimensionless figure ranging between 0 and 1 that shows the fraction of solar radiation hitting the top of the atmosphere that penetrates the atmosphere to reach the Earth's surface. The monthly average clearness index is defined by the equation below

$$K_T = \frac{H_{ave}}{H_{0,ave}}$$

Where Ho,ave represents the extraterrestrial horizontal radiation, it indicates the amount of radiation on a horizontal plane at the peak of Earth's atmosphere, measured in kWh/m²/day. On the other hand, H_ave refers to the monthly average radiation received on Earth's horizontal surface, also expressed in kWh/m²/day. The value of Ho,ave can be determined for any month throughout the year at a specific latitude. Therefore, the equation mentioned can help in calculating one parameter if either H_ave or KT is known. HOMER efficiently performs this calculation each time we enter a value into the monthly data section in the solar asset input window.

### 3.5.11 Renewable Fractions

Eco-friendly segments represent the minute fraction of the energy supplied to the system that originaltest from renewable energy sources. The formula [58] utilized to compute the renewable share is outlined as follows:

$$f_{ren} = 1 - \frac{E_{nonren} - H_{nonren}}{E_{served} - H_{served}} \text{ ....... (1)}$$

Where, $E_{nonren}$ is the non-inexhaustible electrical creation (kWh/yr)

$E_{grid,sales}$the energy offered to the network (kWh/yr) (remembered for Eserved)

$E_{nonren}$is the non-inexhaustible warm creation (kWh/yr)

$E_{served}$is the absolute electrical burden served (kWh/yr)

$H_{served}$is the absolute warm burden served (kWh/yr)

### 3.5.12 Salvage value

To ascertain the salvage value of each component at the conclusion of the project lifespan, HO MER employs the formula:

$$S = Crep\frac{Rrem}{Rcomp} \text{....... (2)}$$

Where S denotes the component's salvage value, Crep refers to its replacement cost, Rem signifies its remaining useful life, and Comp indicates its overall lifespan. For example, the PV array's salvage value will be nonexistent at the end of the project's duration since it has no remaining life if the project lifespan is 20 years and the PV array's lifespan aligns with that at also 20 years. Conversely, if the PV array has a 30-year lifespan, its salvage value will amount to one-third of its replacement cost after the 20-year project.

## 3.6 Hybrid System Configurations

A hybrid energy system combines two or more energy sources, which can include renewable options as well as non-renewable ones, to generate power. This setup ensures that if one source falls short, others can kick in to maintain a steady energy supply, promoting sustainability. It is particularly advantageous in areas where extending the electricity grid is costly, especially in remote regions where connecting to centralized power plants is impractical. By tapping into locally abundant renewable resources, these systems can provide electricity in a sustainable manner, ultimately enhancing the quality of life for local residents. While relying solely on renewable energy can be beneficial, rural communities may face challenges, such as increasing fuel costs, expensive fuel transportation, and larger issues like climate change. Additionally, renewable sources typically have an intermittent output, making it tough to manage energy supply according to demand. To tackle these issues, combining conventional diesel generators with renewable energy sources can improve both the reliability and affordability of power. In summary, a hybrid power system, which incorporates various renewable energy sources along with energy storage solutions, is tailored to meet the unique energy needs of isolated areasthis innovative system seamlessly integrates solar, wind, and tidal energy along with battery storage to deliver reliable, sustainable, and clean electricity for the local community and the fishing industry. A key component is the charging stations for electric fishing boats, ensuring that energy supply remains steady despite the fluctuations commonly associated with renewable sources. The configuration must responsibly meet the energy demands of the island while promoting sustainability.By minimizing diesel generator fuel usage and reducing greenhouse gas emissions, the system efficiently utilizes locally available resources. It addresses power shortages, enhancing the overall sustainability of the power supply. Moreover, it provides quicker access to electricity than waiting for grid expansion, with room to accommodate future capacity growth.Hybrid standalone systems offer adaptability in power control and environmental benefits compared to relying solely on diesel generators. These systems can be scaled up in response to increasing demand, whether through enhanced renewable resources, the rated capacity of diesel generators, or a combination of both. Some components generate DC power, while others produce AC power directly, eliminating the need for a converter.The off-grid boat charging stations are specifically designed to deliver power to electric boats without depending on the electrical grid. Strategically located in remote or waterfront areas, these stations are crucial where grid access may be limited or impractical. Given the intermittent nature of solar and wind energy, a battery bank is essential for storing excess energy generated during sunny or windy conditions. This stored energy serves as a backup during periods of low generation, such as at night or on calm days without wind.The charging stations are equipped with multiple ports for boats to connect and recharge their batteries. The design can cater to various types of electric boats, accommodating different voltage and current specifications. Features like weatherproof enclosures and safety measures are included to protect the equipment from environmental elements.When estimating energy demand, the system must align with the anticipated needs of the electric boats that will utilize the station. This involves calculating the total energy required for charging, taking into account the number of boats, battery size, and the energy necessary for a complete charge.When designing an energy generation and storage system, it’s essential to consider peak charging demand alongside average daily charging cycles. Batteries should be adequately sized to store enough energy for charging boats during times of low solar and wind production. The capacity of the batteries must be able to accommodate peak loads and supply power during nights or on days when renewable energy output is lacking.

**Figure 3.30:-Proposed Hybrid System**

Off-grid boat charging stations need to function independently with minimal human oversight. Reliability is key, so the system should include built-in redundancies for periods of inadequate energy generation. Utilizing automatic switches and controllers will enhance the management of energy sources, allowing the system to draw power from the battery, biogas, or renewable sources as needed to fulfill the station's energy demands.

### 3.6.1 Different Scenarios of the Proposed of Hybrid System

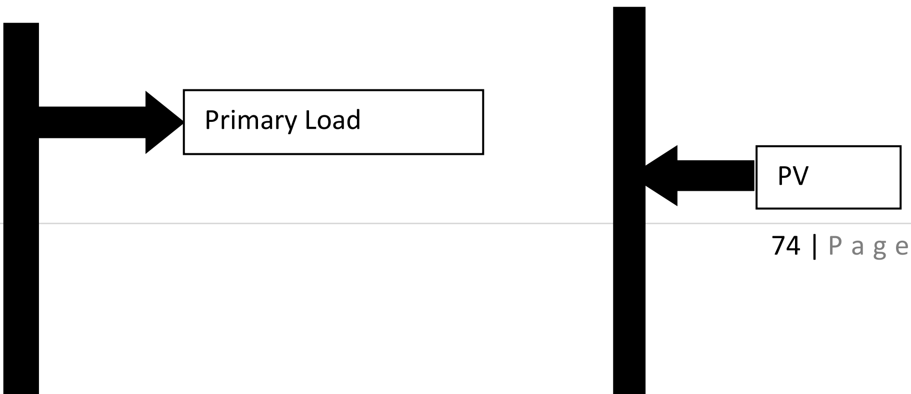
When proposing a hybrid energy system, various scenarios can be considered to evaluate its performance, costs, and efficiency under different conditions. The integration of multiple renewable energy sources, storage technologies, and backup generation can yield different outcomes depending on factors like geographic location, energy demand, available resources, and technological choices. Below are different scenarios that could be used to assess the effectiveness of a proposed hybrid system.By leveraging local resources and integrating renewable energy technologies, hybrid systems support environmental conservation, reduce greenhouse gas emissions, and enhance energy security. They represent a critical step toward achieving sustainable development goals and transitioning to a low-carbon future.

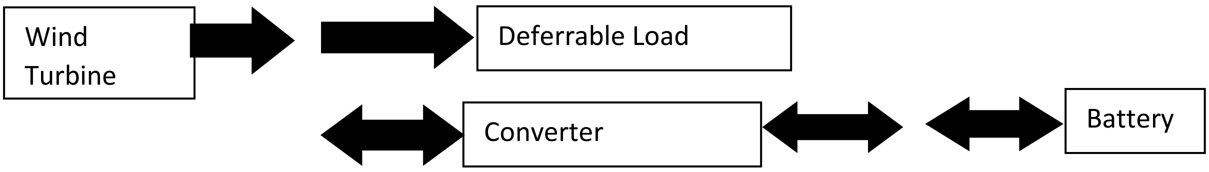
### 3.6.2 Modeling of Renewable Hybrid Energy Systems Components

The modeling of renewable hybrid energy system components enables the development of tailored solutions that are efficient, cost-effective, and environmentally friendly. With the help of advanced simulation tools and optimization frameworks, hybrid systems can be customized to meet diverse energy needs in urban, rural, and industrial settings, contributing to a cleaner and more sustainable future. Modeling renewable hybrid energy systems (HES) involves the integration of various energy components like renewable energy sources, energy storage systems, and backup power solutions to ensure a reliable and efficient energy supply. A hybrid energy system combines two or more energy sources (e.g., solar, wind, biomass) with energy storage devices (e.g., batteries, hydrogen storage) and sometimes a backup generator to form an integrated system that meets energy demand in an off-grid or grid-connected environment.

#### 3.6.2.1 Scenario aWind-photovoltaic Micro Grid system

An off-grid Wind-PV-Microgrid system offers a sustainable, reliable, and independent solution for energy generation in remote or isolated areas. By combining wind and solar energy with battery storage and advanced microgrid controls, these systems ensure continuous power supply without the need for a connection to the main grid. Although the upfront investment can be significant, the long-term benefits in terms of energy independence, environmental sustainability, and cost savings make this solution an attractive option for off-grid applications. Proper system design, sizing, and energy management are crucial to ensuring the system is efficient, reliable, and cost-effective.



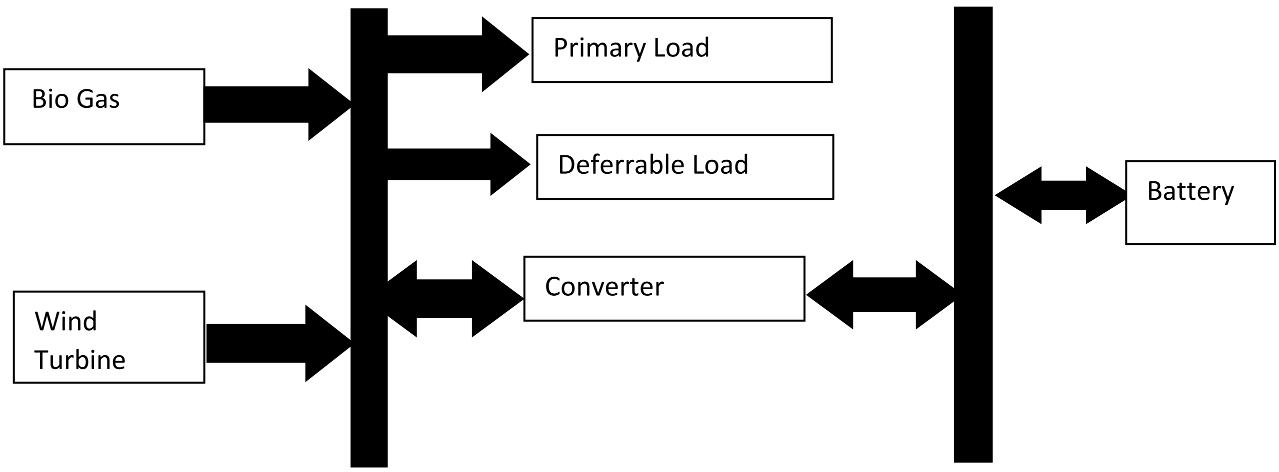



**ACDC**

**Figure 3.31:-Wind-photovoltaic Micro Grid system**

### 3.6.2.2 Scenario B - Wind-Bio Gas Micro Grid System Energy System:-

An Off-Grid Wind-Bio Gas MicrogridSystem is an integrated energy solution that combines wind powerandbiogas energyto generate, store, and distribute electricity in areas that are not connected to the central grid. This system operates autonomously, providing energy to remote communities, agricultural operations, or industrial facilities, relying on renewable and sustainable sources of energy. By combining wind and biogas, the system benefits from the complementary nature of both energy sources, ensuring a continuous and reliable power supply despite the intermittency of wind power or biogas production.




**ACDC**

**Figure 3.32:- Wind-Bio Gas Micro Grid Energy System**

### 3.6.2.3 Scenario C Solar-Biogas Micro grid energy system :-

An Off-Grid Solar-Biogas Micro grid Energy System is an integrated renewable energy solution designed to provide electricity and sometimes heat to remote, rural, or off-grid locations. It combines the complementary benefits of solar power and biogas to ensure a continuous, sustainable, and reliable energy supply, even in areas without access to the main electricity grid. This system is particularly beneficial for communities, agricultural operations, or industrial facilities located in remote areas, as it reduces dependency on fossil fuels and helps manage waste while generating renewable energy.

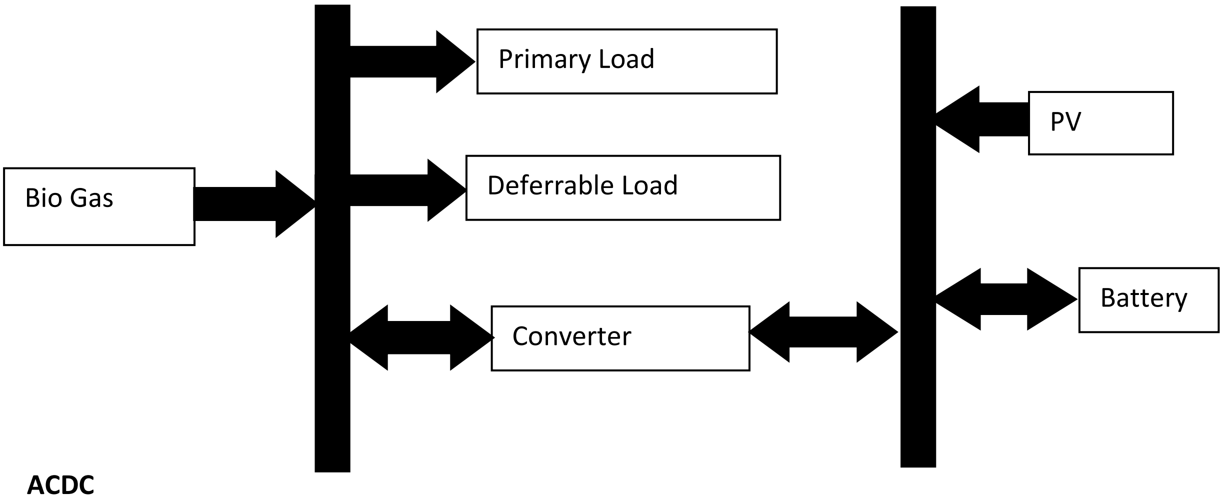
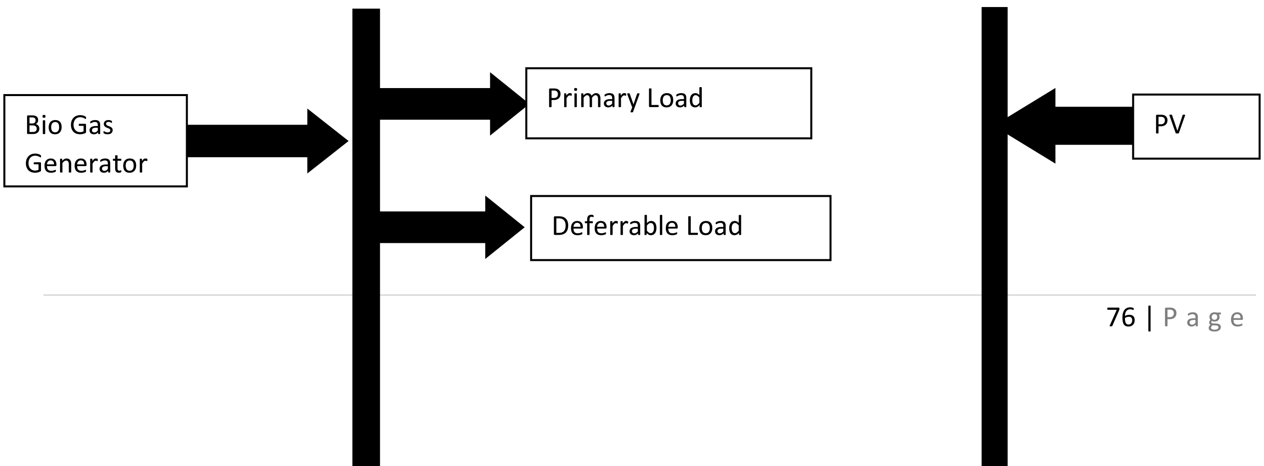



**Figure 3.33:- Solar-Biogas Microgrid energy system**

### 3.6.2.4 Scenario D- Hybrid Wind-Solar-Bio Gas Micro grid Energy System :-

An Off-Grid Hybrid Wind-Solar-Biogas Energy System is a sophisticated and resilient renewable energy solution that integrates three complementary energy sources—wind power, solar power, and biogas—to supply electricity (and potentially heat) to areas that are not connected to the central grid. This system provides a more reliable and sustainable energy supply for remote, rural, or off-grid locations where access to conventional power infrastructure is limited or unavailable. By combining wind, solar, and biogas in a hybrid configuration, the system takes advantage of the complementary nature of these renewable resources, ensuring a continuous power supply, even when one source is unavailable or intermittent. This system is particularly beneficial for isolated communities, agricultural operations, and industrial sites that require a reliable, renewable, and autonomous energy solution.



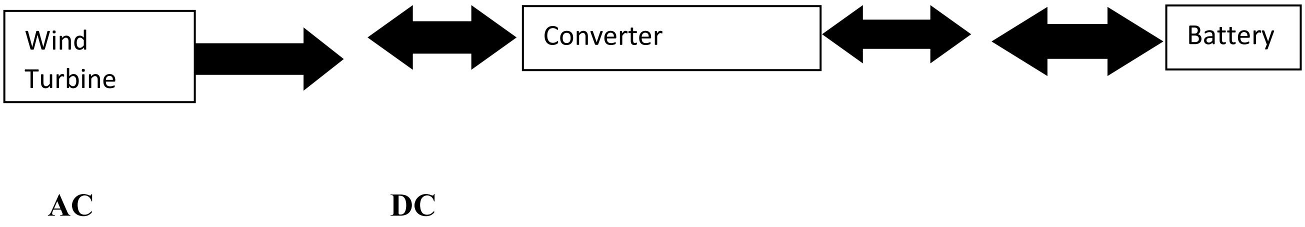



**Figure 3.34:- Hybrid Wind-Solar-Bio Gas Micro grid Energy System**

**4.6.3 Conclusion:-**

Renewable energy options are ideal for off-grid systems, as they provide customized solutions for the unique challenges of generating and maintaining power in areas that lack connection to the main electrical grid. Each type of renewable energy comes with distinct features that make it suitable for different environmental conditions, resource availability, and energy needs. By suggesting a variety of renewable options, we can ensure that the system remains sustainable while effectively utilizing diverse natural resources.

In addition, a mix of technologies enhances economic feasibility based on local conditions and available budgets. For instance, combining solar and wind or hydro and biomass can lead to hybrid systems that improve reliability, efficiency, and sustainability. This is especially valuable for off-grid communities, where energy demands can fluctuate. By offering a range of renewable energy solutions, we can design off-grid systems that optimize resource use, increase reliability, and promote sustainable development tailored to the specific challenges of remote or isolated areas.

# CHAPTER 4
# SIMULATION RESULT AND DISCUSSION

**4.1 Introduction**

This chapter delves into the overall findings and assessment of HOMER. The HOMER simulations produce four distinct scenarios. This section investigates the optimization outcomes that were achieved. This is typically presented in a clear, objective manner with data and charts that describe the system's performance over time. Additionally, the four scenarios are utilized to evaluate the social, environmental, and financial dimensions. The optima 4solar wind, biogas microgrid system choice is then scrutinized considering power generation, cash flow, operational and maintenance expenses, among other parameters.

### 4.2 HOMER

#### 4.2.1 Introduction

HOMER (Hybrid Optimization of Multiple Energy Resources) is a robust software solution designed for the strategic planning and enhancement of microgrids and distributed energy systems, which encompass off-grid and hybrid renewable setups. This tool empowers users to simulate a range of energy sources—including solar, wind, battery storage, and diesel generators—to discover configurations that provide the best balance of cost and reliability. It's widely utilized for projects involving off-grid energy systems, microgrids, distributed energy technologies, and hybrid renewable energy initiatives.

#### 4.2.2 Key Features of HOMER Modeling

**1. Diverse Energy Sources**: HOMER accommodates a variety of energy options, including renewables like solar, wind, hydropower, and biogas, along with traditional sources such as diesel generators and grid power.

**2. Optimization Capabilities:** The software optimizes system configurations to identify the most cost-effective and reliable solutions. It assesses different combinations of energy sources, storage solutions, and generators while factoring in both initial capital and ongoing operational costs.

**3. Hourly Simulations:** HOMER conducts models on an hourly basis, enabling a thorough evaluation of performance and costs across various times throughout the year. This is particularly crucial for systems with variable energy generation, such as those reliant on solar and wind.

**4. Battery Storage Integration:** Users can incorporate battery storage systems into their models, allowing for optimization of battery sizing, charging/discharging cycles, and management of energy storage expenses.

**5. Economic Assessments:** HOMER provides comprehensive financial analyses, including calculations for Net Present Cost (NPC), Levelized Cost of Energy (LCOE), and other monetary metrics, helping users gauge the long-term economic viability of their energy systems.

**6. Sensitivity Analysis:** The software offers sensitivity analysis, demonstrating how changes in input parameters (such as fuel prices, interest rates, and system costs) can impact the system's performance and economic viability.

**7. Scenario Modeling:** HOMER enables users to explore multiple scenarios to understand how various design decisions like the size of renewable resources, battery capacities, or generator outputs can affect overall system performance.

### 4.2.3 Key Steps in HOMER Modeling:

**1. Defining the System Requirements**:

**Load Profile:** Enter the energy demand or load profile (hourly or daily) relevant to your system, whether it's for an off-grid boat charging station, a community, or a microgrid.

**System Constraints:**Specify the operational limitations, including the desired reliability level, backup power needs, and acceptable fuel consumption limits.

**2. Inputting Energy Sources:**

**Renewable Energy:** Provide data on renewable sources such as solar radiation and wind speeds, along with any other local conditions (temperature, precipitation, etc.).

**Conventional Power:** If necessary, incorporate conventional generators (like diesel or biogas) into the model, detailing their specifications including fuel consumption and operational hours.

**Storage Systems**: Outline the characteristics of batteries, covering aspects like capacity, charge/discharge rates, efficiency, and associated costs.

**3. Running the Simulation:**HOMER will execute the simulation based on the inputs you've provided, leveraging optimization algorithms to assess different mixes of energy sources and storage options. The software simulates the energy system over a set duration (usually one year) to evaluate its reliability, costs, and overall performance.

**4.Analyzing the Results:**

**Optimization Results:**Study the optimized system configuration, highlighting the ideal mix of energy sources, storage solutions, and generator sizes, along with their respective costs and performance indicators.

**Economic Metrics:** HOMER generates various economic outputs, including Net Present Cost (NPC), Levelized Cost of Energy (LCOE), fuel consumption, and emissions. These will help assess the financial and environmental feasibility of the system.

**Sensitivity Analysis:** Conduct a sensitivity analysis to see how variations in input factors (like fuel prices or solar panel costs) impact system performance and economic metrics.

**5. Scenario Comparison:**You can compare various scenarios (for instance, evaluating a solar-only design versus a hybrid setup using wind, biogas, and storage) to identify which configuration best meets the energy requirements while optimizing for cost and performance.

### 4.3 Different Scenarios of Various Parameters of Hybrid Scenarios

The entire setup has been designed as an autonomous system, consisting of solar PV panels, a wind turbine, a diesel generator, a biogas generator, a battery, and a converter. This system en compasses two buses: AC and DC. On the DC bus side, a battery accumulates the output energy from the solar PV system. A converter facilitates the conversion from AC to DC. The operation of the system is governed by the converter, which prioritizes solar, wind, biogas, diesel, and the storage battery. HOMER simulates various configurations of energy system components. The design's complexity, computation duration, and total number of potential values are influenced by the number of parameters considered.

### 4.4 Conclusion

HOMER (Hybrid Optimization of Multiple Energy Resources) modeling is an exceptional tool designed for crafting and fine-tuning off-grid energy systems. It allows for a thorough assessment of different renewable energy technologies, energy storage options, and backup alternatives, resulting in solutions that are not only cost-effective but also reliable and sustainable—customized for specific locations and unique needs.The strength of HOMER lies in its capacity to simulate hybrid systems that combine solar, wind, hydro, biomass, and other energy sources, effectively tackling the challenges of intermittency and ensuring optimal energy generation. By analyzing resource availability, load demand, economic constraints, and environmental impacts, HOMER delivers crucial insights for system design, sizing, and long-term viability.

### 4.4 Scenario A Solar PV and Wind Micro grid system

#### 4.4.1 Introduction

Creating a PV (Photovoltaic) and wind-based microgrid system for NijhumDwip, a remote island in Bangladesh, requires careful planning due to the island's geographic, environmental, and socioeconomic context. Here is a detailed outline of how such a system can be designed and implemented:

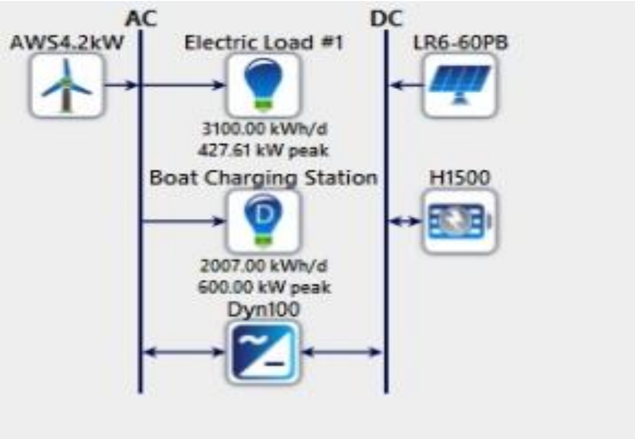



**Figure4.1 :- Solar PV and Wind Micro grid systemScenario A**

**Table 4.1 System ArchitectureScenario A**

| **Component** | **Name** | **Size** | **Unit** |
|---|---|---|---|
| **PV** | LONGi Solar LR6-60PB | 1,256 | kW |
| **Storage** | Hoppecke 12 OPzS 1500 | 481 | strings |
| **Wind turbine** | AWS HC 4.2kW Wind Turbine | 239 | ea. |
| **System converter** | Dynapower SPS - 100 | 555 | kW |
| **Dispatch strategy** | HOMER Cycle Charging | | |

### 4.4.2 Cost Summary

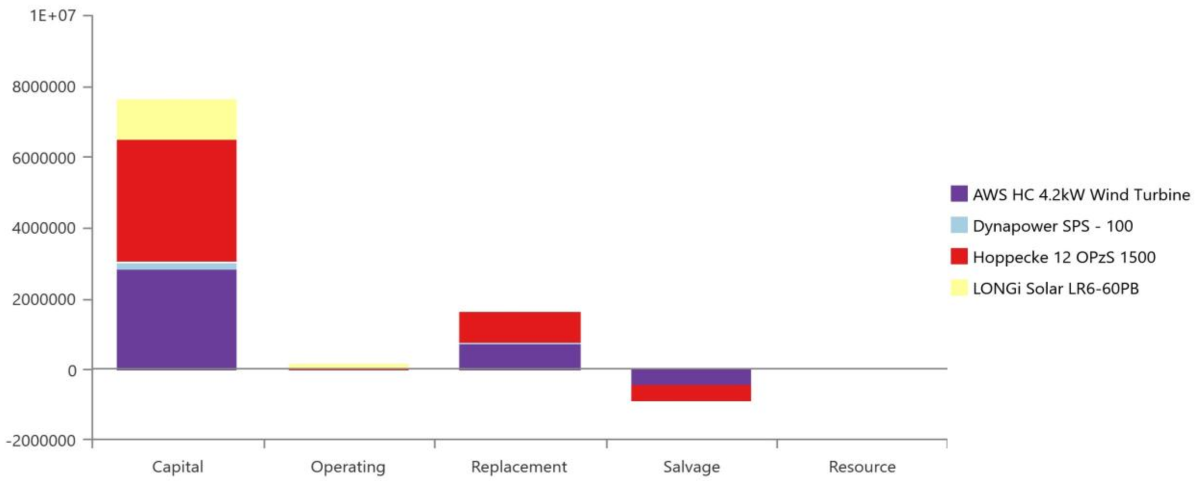



**Figure 4.2 Cost summary for Scenario A**

**Table 4.2 Net Present CostsScenario A**

| **Name** | **Capital** | **Operating** | **Replacement** | **Salvage** | **Resource** | **Total** |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $2.87M | $30,897 | $761,950 | -$429,407 | $0.00 | $3.23M |
| **Dynapower SPS - 100** | $161,026 | $0.00 | $54,184 | -$10,198 | $0.00 | $205,013 |
| **Hoppecke 12 OPzS 1500** | $3.46M | $18,654 | $828,070 | -$466,671 | $0.00 | $3.84M |
| **LONGi Solar LR6-60PB** | $1.13M | $162,432 | $0.00 | $0.00 | $0.00 | $1.29M |
| **System** | $7.62M | $211,983 | $1.64M | -$906,276 | $0.00 | $8.57M |

**Table 4.3 Annualized CostsScenario A**

| **Name** | **Capital** | **Operating** | **Replacement** | **Salvage** | **Resource** | **Total** |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $221,852 | $2,390 | $58,940 | -$33,217 | $0.00 | $249,966 |
| **Dynapower SPS - 100** | $12,456 | $0.00 | $4,191 | -$788.86 | $0.00 | $15,859 |
| **Hoppecke 12 OPzS 1500** | $267,894 | $1,443 | $64,055 | -$36,099 | $0.00 | $297,293 |
| **LONGi Solar LR6-60PB** | $87,475 | $12,565 | $0.00 | $0.00 | $0.00 | $100,040 |

### 4.4.3 Cash FlowScenario A

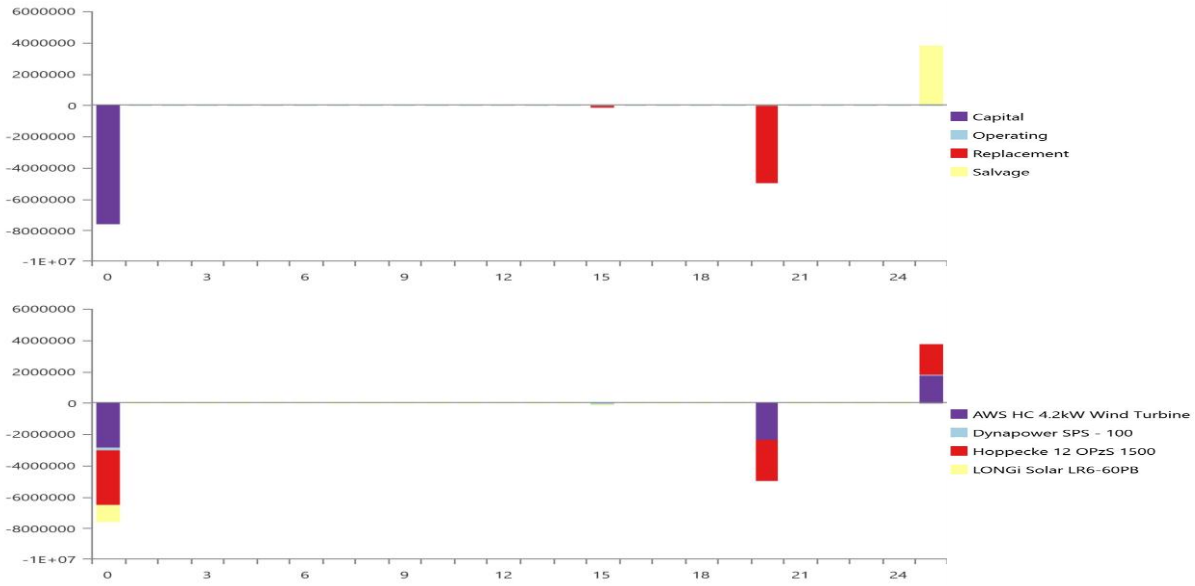



**Figure: - 4.3 cash flow Scenario A**

### 4.4.4 Electric Consumptionfor Scenario A

Table 4.4 Excess and Unmet for Scenario A

| Quantity | Value | Units |
|---|---|---|
| Unmet Electric Load | 1,483 | kWh/yr |
| Excess Electricity | 1,266,150 | kWh/yr |
| Capacity Shortage | 1,842 | kWh/yr |

Table 4.5 Production Summary for Scenario A

| Component | Production (kWh/yr) | Percent |
|---|---|---|
| LONGi Solar LR6-60PB | 1,673,334 | 51.3 |
| AWS HC 4.2kW Wind Turbine | 1,588,012 | 48.7 |
| Total | 3,261,346 | 100 |

Table 4.6 Consumption Summary for Scenario A

| Component | Consumption (kWh/yr) | Percent |
|---|---|---|
| AC Primary Load | 1,131,005 | 60.7 |
| Deferrable Load | 731,567 | 39.3 |
| DC Primary Load | 0 | 0 |
| Total | 1,862,572 | 100 |

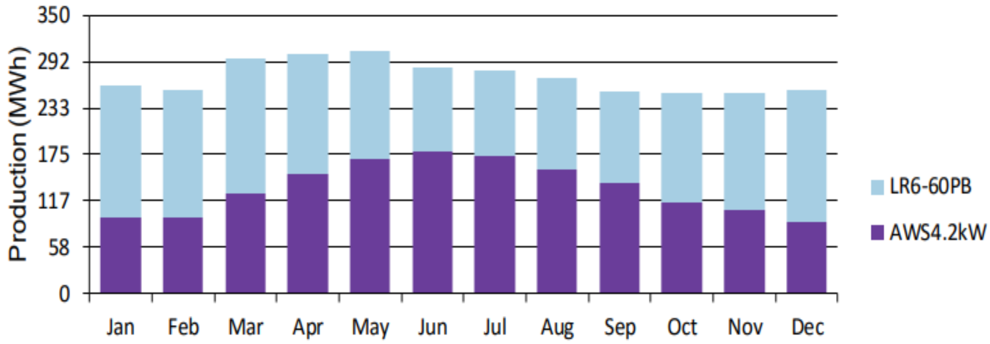



**Figure4.4:- Electric Consumption for Scenario A**

### 4.4.5 Wind Turbine: AWS HC 4.2kW Wind Turbine for Scenario A

Table 4.7Wind Turbine Electrical Summary for Scenario A

| Quantity | Value | Units |
|---|---|---|
| Maximum Output | 1,305 | kW |
| Minimum Output | 0 | kW |
| Wind Penetration | 140 | % |
| Levelized Cost | 0.157 | $/kWh |
| Hours of Operation | 7,357 | hrs/yr |

Table 4.8AWS HC 4.2kW Wind Turbine Statistics for Scenario A

| Quantity | Value | Units |
|---|---|---|
| Total Rated Capacity | 1,004 | kW |
| Capacity Factor | 18.1 | % |
| Mean Output | 181 | kW |
| Total Production | 1,588,012 | kWh/yr |

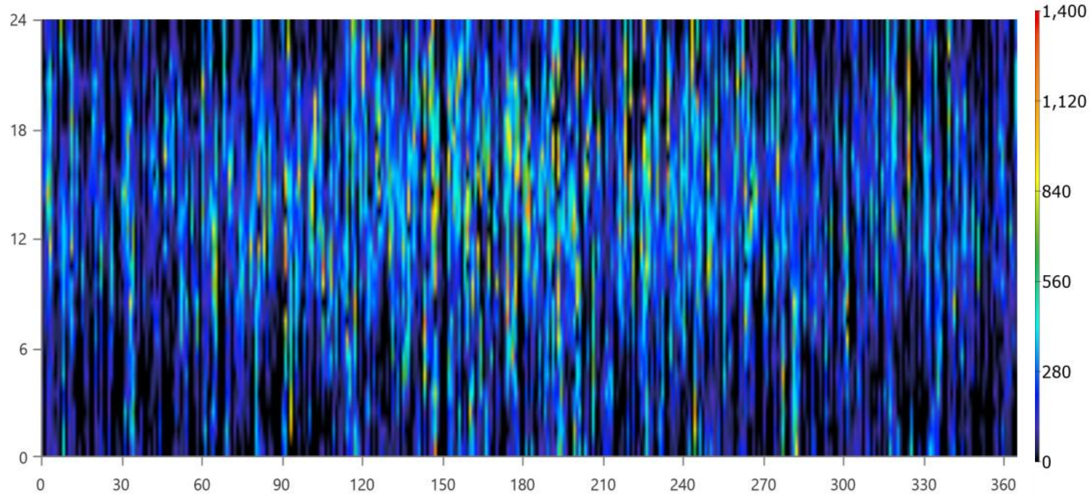



**Figure 4.5:- AWS HC 4.2kW Wind Turbine Output (kW) for Scenario A**

### 4.4.6 PV: LONGi Solar LR6-60PB for Scenario A

**Table 4.9LONGi Solar LR6-60PB Electrical Summary for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| Maximum Output | 1,046 | kW |
| Minimum Output | 0 | kW |
| Hours of Operation | 4,370 | hrs/yr |
| PV Penetration | 148 | % |
| Clipped production | 0 | kWh |
| Levelized Cost | 0.0598 | $/kWh |

**Table 4.10LONGi Solar LR6-60PB Statistics for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| Mean Output | 4,584 | kWh/d |
| Rated Capacity | 1,256 | kW |
| Capacity Factor | 15.2 | % |
| Mean Output | 191 | kW |
| Total Production | 1,673,334 | kWh/yr |

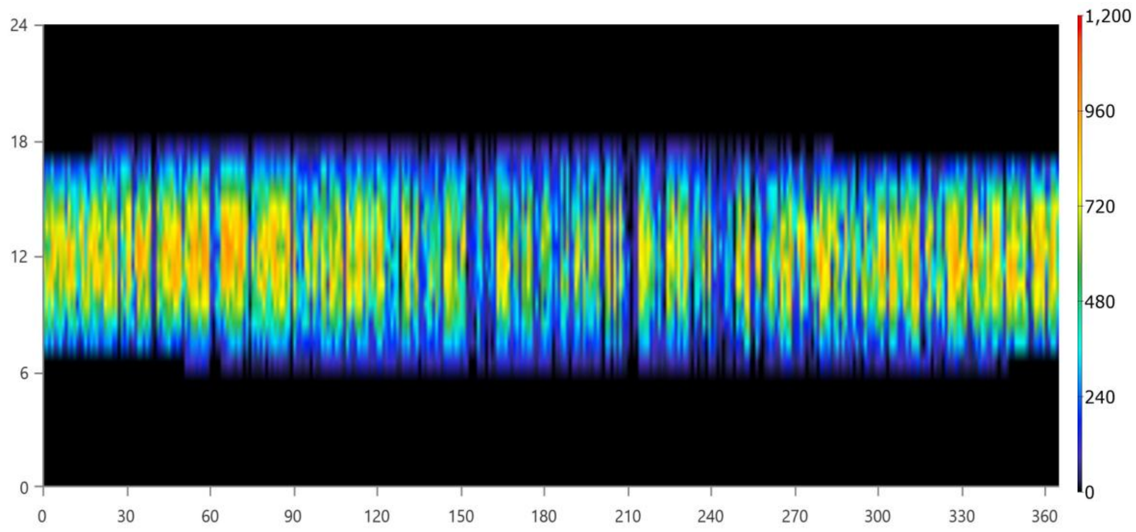



**Figure 4.6:-LONGi Solar LR6-60PB Output (kW) for Scenario A**

### 4.4.7 Storage: Hoppecke 12 OPzS 1500 for Scenario A

**Table 4.11Hoppecke 12 OPzS 1500 Properties for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| Batteries | 2,886 | qty. |
| Strings in Parallel | 481 | strings |
| String Size | 6.00 | batteries |
| Bus Voltage | 12.0 | V |

**Table 4.12Hoppecke 12 OPzS 1500 Result Data for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| Energy In | 698,808 | kWh/yr |
| Average Energy Cost | 0 | $/kWh |
| Energy Out | 601,131 | kWh/yr |
| Losses | 97,845 | kWh/yr |
| Storage Depletion | 168 | kWh/yr |
| Annual Throughput | 648,216 | kWh/yr |
| Average Daily EFCs | 0.171 | 1/day |
| Annual EFCs | 62.6 | 1/yr |

**Table 4.13Hoppecke 12 OPzS 1500 Statistics for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| Storage Wear Cost | 0.191 | $/kWh |
| Autonomy | 34.1 | hr |
| Usable Nominal Capacity | 7,252 | kWh |
| Nominal Capacity | 10,360 | kWh |
| Lifetime Throughput | 12,964,321 | kWh |
| Expected Life | 20.0 | yr |

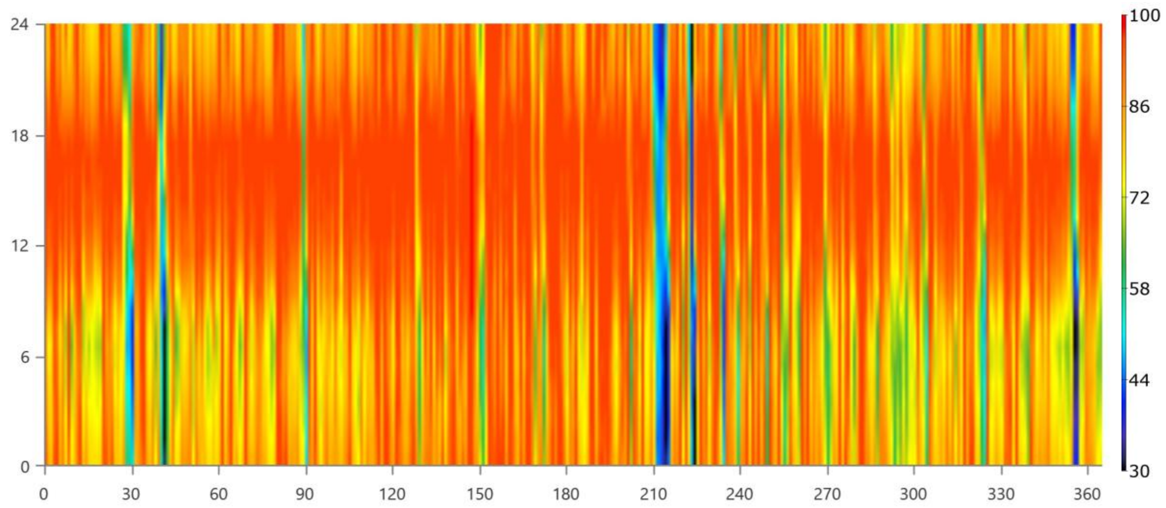



**Figure 4.7:- Hoppecke 12 OPzS 1500 State of Charge (%)forScenario A**

### 4.4.8 Dynapower SPS - 100 Electrical Summary for Scenario A

**Table 4.14Dynapower SPS - 100 Electrical Summary for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| **Hours of Operation** | 5,778 | hrs/yr |
| **Energy Out** | 842,943 | kWh/yr |
| **Energy In** | 873,516 | kWh/yr |
| **Losses** | 30,573 | kWh/yr |

**Table 4.15Dynapower SPS - 100 Statistics for Scenario A**

| Quantity | Value | Units |
|---|---|---|
| **Capacity** | 555 | kW |
| **Minimum Output** | 0 | kW |
| **Mean Output** | 96.2 | kW |
| **Maximum Output** | 527 | kW |
| **Capacity Factor** | 17.3 | % |

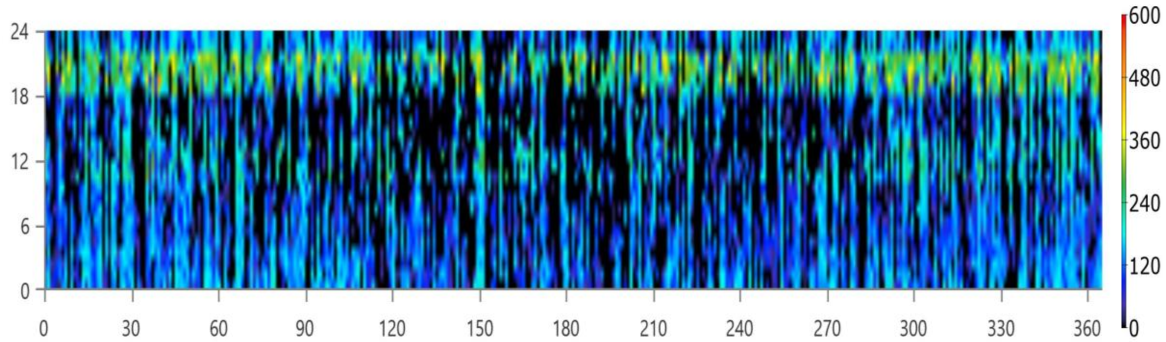



**Figure 4.8:- Dynapower SPS - 100 Inverter Output (kW) for Scenario A**

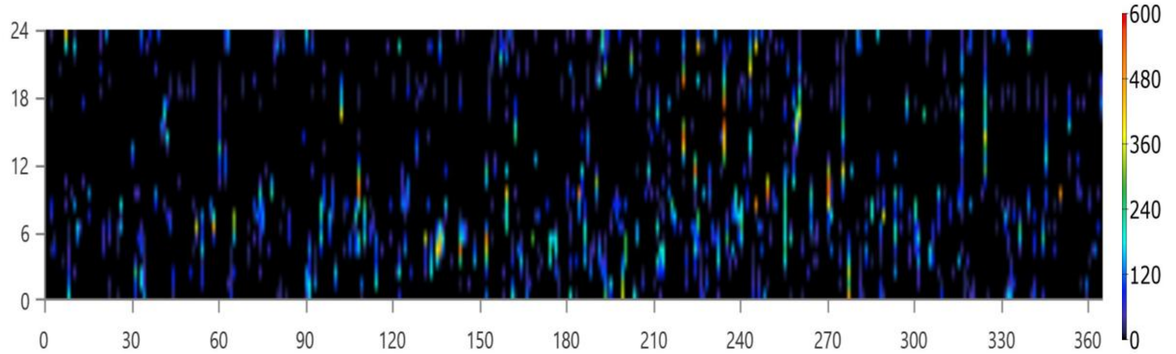



**Figure 4.9:- Dynapower SPS - 100 Rectifier Output (kW) for Scenario A**

**Table 4.16Renewable Summary for Scenario A**

| **Capacity-based metrics** | **Value** | **Unit** |
|---|---|---|
| **Usable renewable capacity divided by total capacity** | 100 | % |
| **Nominal renewable capacity divided by total nominal capacity** | 100 | % |
| **Energy-based metrics** | **Value** | **Unit** |
| **Total renewable production divided by load** | 175 | % |
| **Total renewable production divided by generation** | 100 | % |
| **One minus total nonrenewable production divided by load** | 100 | % |
| **Peak values** | **Value** | **Unit** |
| **Renewable output divided by load (HOMER standard)** | 1,145 | % |
| **One minus nonrenewable output divided by total load** | 100 | % |
| **Renewable output divided by total generation** | 100 | % |

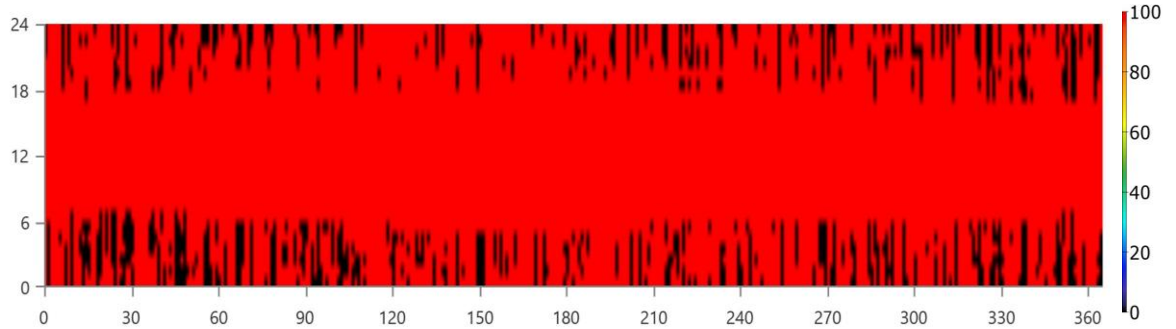



**Figure 4.10:- Instantaneous Renewable Output Percentage of Total Generation for Scenario A**

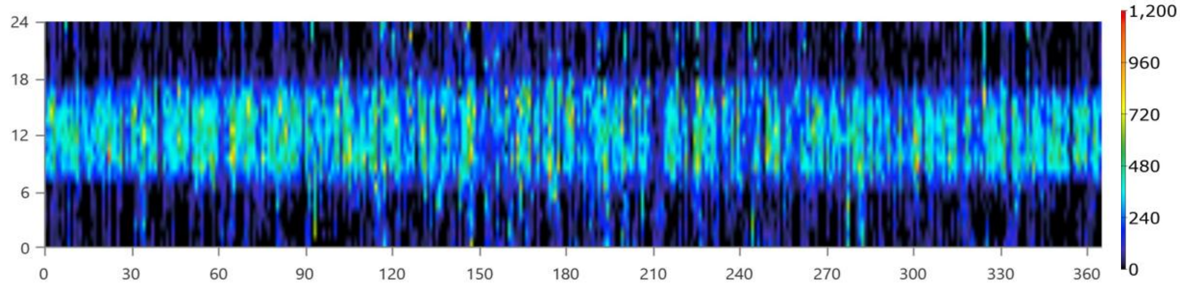



**Figure 4.11:-Instantaneous Renewable Output Percentage of Total Load for Scenario A**

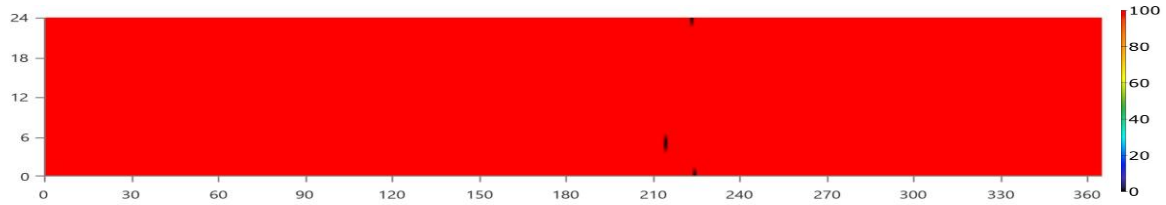


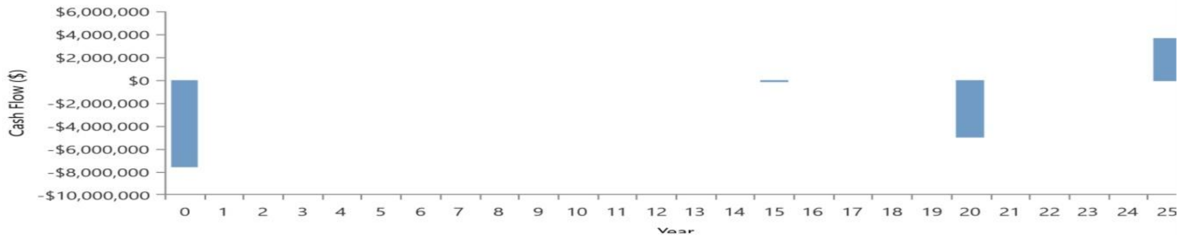

**Figure 4.12:- 100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load**

### 4.4.9Compare Economics for Scenario A

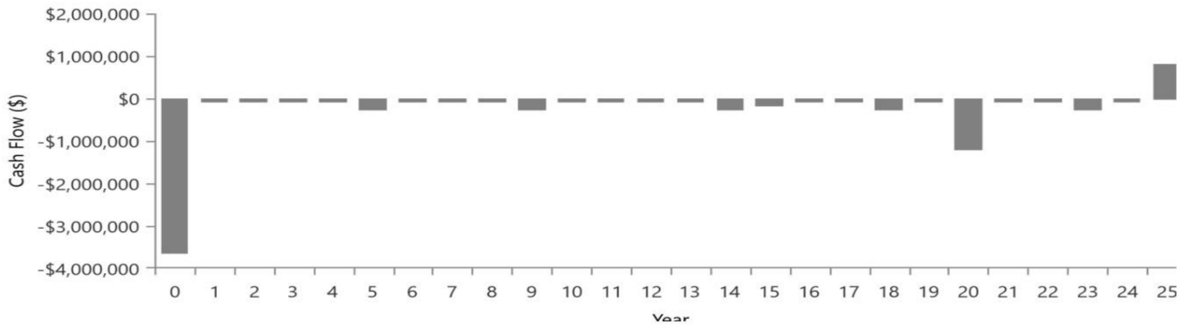
**Table 4.17Simple payback (yr):N/A for Scenario A**

| | **Base System** | **Proposed System** |
|---|---|---|
| **Net Present Cost** | $5.63M | $8.57M |
| **CAPEX** | $3.67M | $7.62M |
| **LCOE (per kWh)** | $0.234 | $0.356 |
| **OPEX** | $151,342 | $73,480 |
| **Fuel Consumption (L/yr)** | 2,369 | 0 |
| **CO2 Emitted (kg/yr)** | 427 | 0 |

### 4.4.10Proposed Annual Nominal Cash Flows for Scenario A




### 4.4.11 Base System Annual Nominal Cash Flows for Scenario A




### 4.4.12 Cumulative Discounted Cash Flows for Scenario A

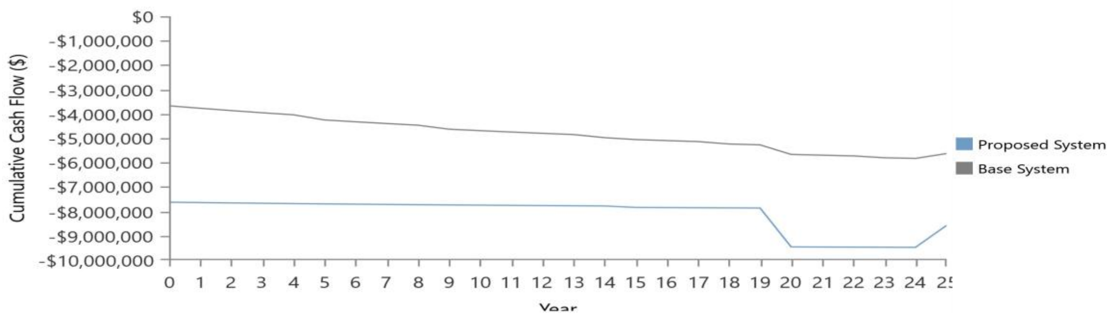



**Figure 4.13:- Demo Solar PV and Wind Micro grid proposed system**

### 4.4.13 Conclusion

The integration of solar and wind energy for off-grid generation in remote locations like NijhumDwip, Bangladesh, has demonstrated solid technical feasibility. This system is designed to ensure consistent energy production, taking full advantage of the abundant availability of these renewable resources year-round. With a levelized cost of energy (LCOE) at $0.356, it showcases strong economic potential, particularly when stacked against the high and fluctuating costs associated with fossil fuel energy. While the upfront investment in solar panels, wind turbines, and batteries may be significant, the long-term savings on fuel expenses, along with possible subsidies or incentives for renewable energy initiatives, make this system an appealing choice for off-grid regions.

### 4.5 Scenario B Wind - Biogas Micro grid system

### 4.5.1 Introduction

Designing a wind-biogas hybrid microgrid system presents a forward-thinking solution for delivering sustainable energy to rural or remote locations like NijhumDwip. By harnessing wind energy alongside biogas, we can ensure a reliable power supply, particularly during times of low wind. Our proposal includes the installation of an additional 2,211 kWh battery capacity and an increase in wind generation capacity by 1,390 kW. Implementing these enhancements can lower your annual operating costs to just $125,130.

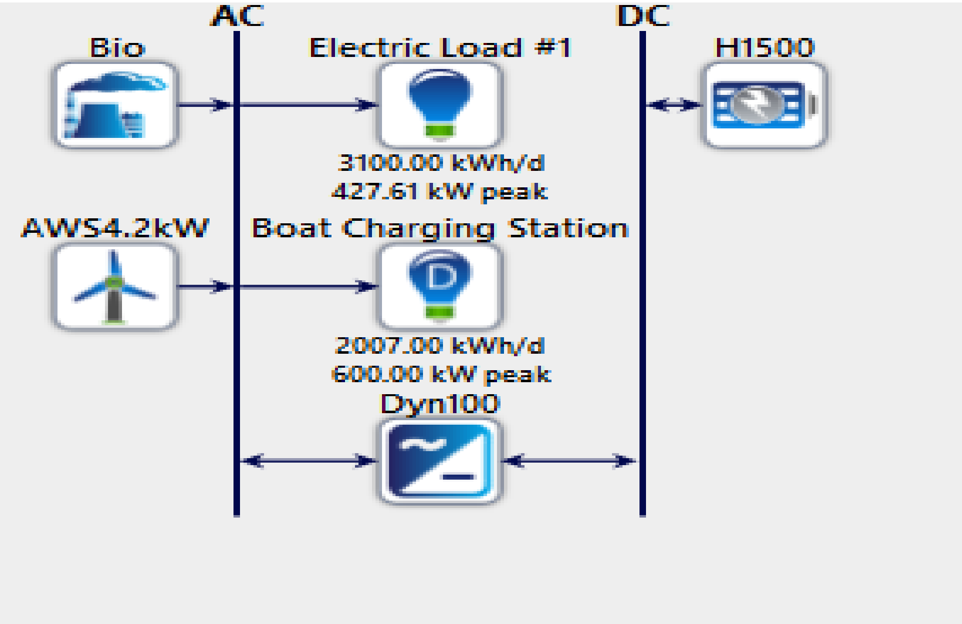



**Fig. 4.14Scenario B Wind - Biogas Micro grid system**

**Table 4.18System Architecture for Scenario B**

| **Component** | **Name** | **Size** | **Unit** |
|---|---|---|---|
| **Generator** | Generic Biogas Genset | 170 | kW |
| **Wind turbine** | AWS HC 4.2kW Wind Turbine | 346 | ea. |
| **Storage** | Hoppecke 12 OPzS 1500 | 300 | strings |
| **System converter** | Dynapower SPS - 100 | 332 | kW |
| **Dispatch strategy** | HOMER Load Following | | |

### 4.5.2 Cost Summary

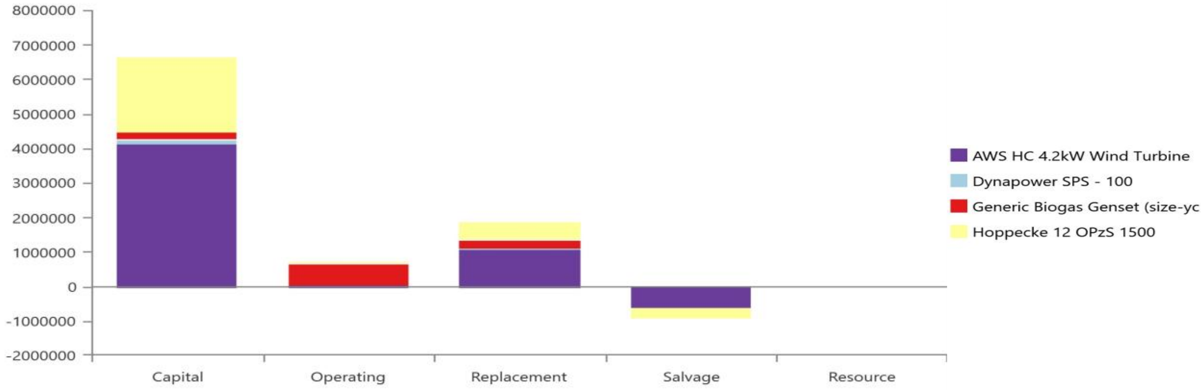



**Figure 4.15 Cost Summary Scenario B**

**Table 4.19Net Present CostsScenario B**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $4.15M | $44,729 | $1.10M | -$621,653 | $0.00 | $4.68M |
| **Dynapower SPS - 100** | $96,221 | $0.00 | $32,378 | -$6,094 | $0.00 | $122,505 |
| **Generic Biogas Genset** | $204,000 | $637,107 | $219,546 | -$13,790 | $0.00 | $1.05M |
| **Hoppecke 12 OPzS 1500** | $2.16M | $11,635 | $516,468 | -$291,063 | $0.00 | $2.40M |
| **System** | $6.61M | $693,471 | $1.87M | -$932,600 | $0.00 | $8.24M |

**Table 4.20Annualized CostsScenario B**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $321,175 | $3,460 | $85,328 | -$48,088 | $0.00 | $361,875 |
| **Dynapower SPS - 100** | $7,443 | $0.00 | $2,505 | -$471.38 | $0.00 | $9,476 |
| **Generic Biogas Genset** | $15,780 | $49,283 | $16,983 | -$1,067 | $0.00 | $80,979 |
| **Hoppecke 12 OPzS 1500** | $167,085 | $900.00 | $39,951 | -$22,515 | $0.00 | $185,422 |
| **System** | $511,484 | $53,643 | $144,766 | -$72,141 | $0.00 | $637,753 |

### 4.5.3 Cash FlowScenario B

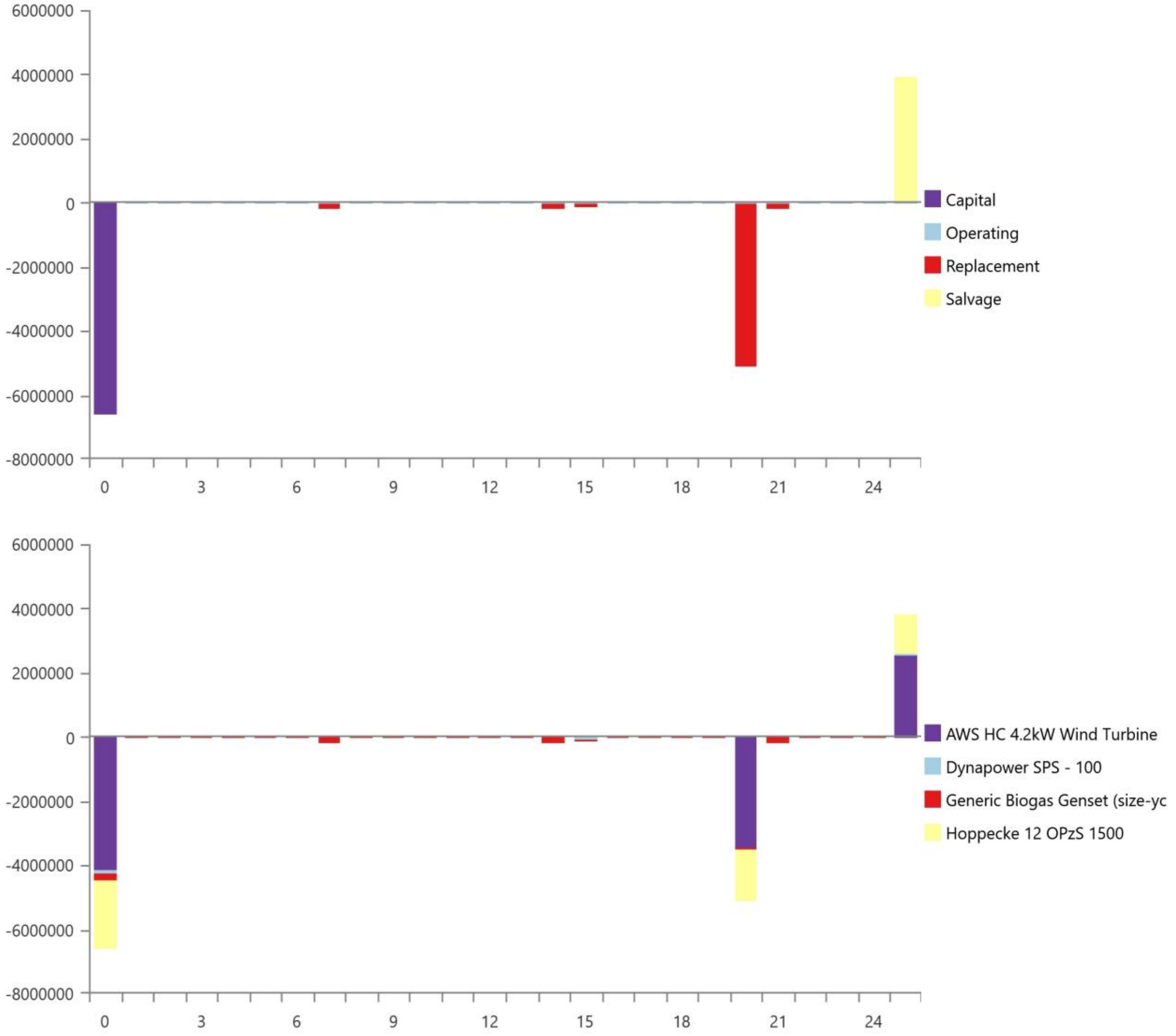



**Figure: -4.16 Cash flow Scenario B**

### 4.5.4 Electrical Consumption

**Table 4.21Excess and UnmetScenario B**

| Quantity | Value | Units |
|---|---|---|
| Unmet Electric Load | 1,558 | kWh/yr |
| Excess Electricity | 844,980 | kWh/yr |
| Capacity Shortage | 1,846 | kWh/yr |

**Table 4.22Production SummaryScenario B**

| Component | Production (kWh/yr) | Percent |
|---|---|---|
| Generic Biogas Genset | 463,839 | 16.8 |
| AWS HC 4.2kW Wind Turbine | 2,298,963 | 83.2 |
| Total | 2,762,801 | 100 |

Table 4.23Consumption SummaryScenario B

| Component | Consumption (kWh/yr) | Percent |
|---|---|---|
| DC Primary Load | 0 | 0 |
| AC Primary Load | 1,131,126 | 60.7 |
| Deferrable Load | 731,371 | 39.3 |
| Total | 1,862,497 | 100 |

This microgrid requires 5103 kWh/day and has a peak of 507 kW. In the proposed system, the following generation sources serve the electrical load.

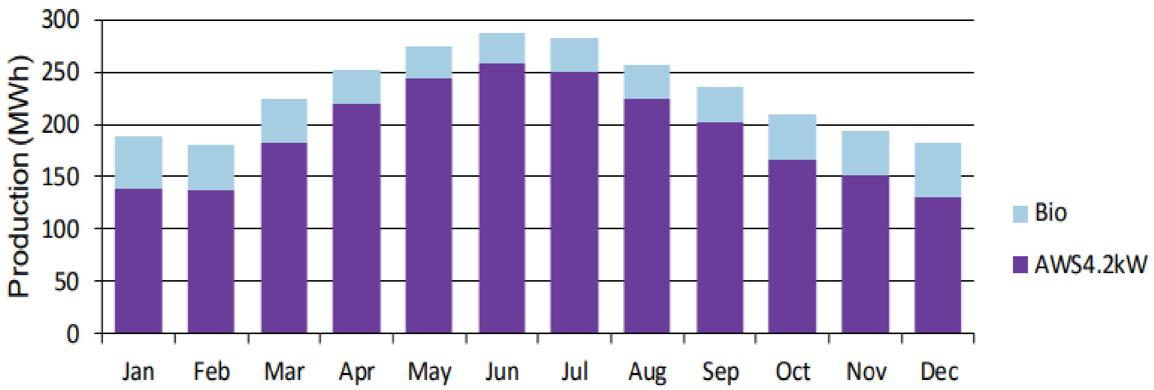



**Figure 4.17:- Biogas wind Microgrid Electricity Production Output**

### 4.5.5 Generator: Generic Biogas Genset (size-your-own) (Biogas)

Table 4.24Generic Biogas GensetElectrical SummaryScenario B

| Quantity | Value | Units |
|---|---|---|
| Electrical Production | 463,839 | kWh/yr |
| Minimum Electrical Output | 85.0 | kW |
| Mean Electrical Output | 160 | kW |
| Maximum Electrical Output | 170 | kW |

Table 4.25Generic Biogas Genset Fuel SummaryScenario B

| Quantity | Value | Units |
|---|---|---|
| Specific Fuel Consumption | 2.11 | kg/kWh |
| Fuel Consumption | 1,396 | tons/yr |
| Mean Electrical Efficiency | 31.1 | % |
| Fuel Energy Input | 1,492,578 | kWh/yr |

Table 4.26Generic Biogas Genset (size-your-own) StatisticsScenario B

| Quantity | Value | Units |
|---|---|---|
| Number of Starts | 736 | starts/yr |
| Hours of Operation | 2,899 | hrs/yr |
| Capacity Factor | 31.1 | % |
| Operational Life | 6.90 | yr |
| Marginal Generation Cost | 0 | $/kWh |
| Fixed Generation Cost | 24.7 | $/hr |

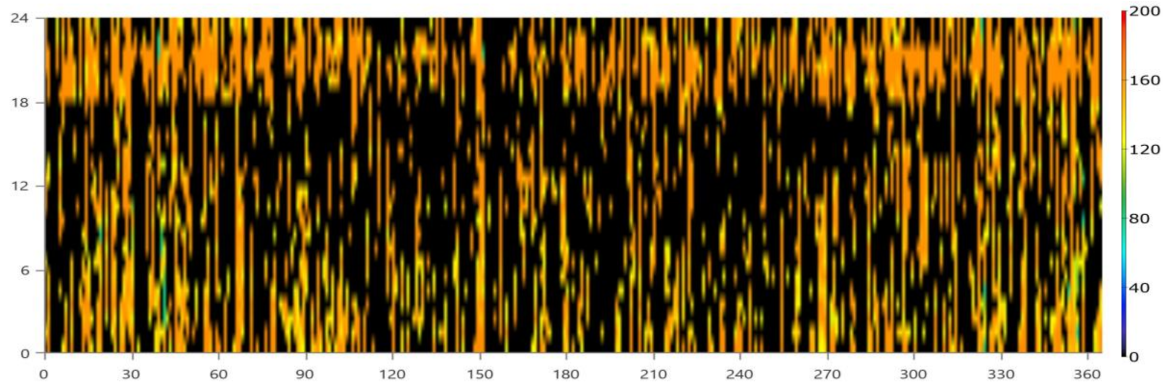



**Figure 4.18:-Generic Biogas Genset (size-your-own) Output (kW)**

### 4.5.6 Wind Turbine: AWS HC 4.2kW Wind Turbine

Table 4.27AWS HC 4.2kW Wind Turbine Electrical SummaryScenario B

| Quantity | Value | Units |
|---|---|---|
| Maximum Output | 1,890 | kW |
| Minimum Output | 0 | kW |
| Wind Penetration | 203 | % |
| Levelized Cost | 0.157 | $/kWh |
| Hours of Operation | 7,357 | hrs/yr |

Table 4.28AWS HC 4.2kW Wind Turbine StatisticsScenario B

| Quantity | Value | Units |
|---|---|---|
| Total Rated Capacity | 1,453 | kW |
| Capacity Factor | 18.1 | % |
| Mean Output | 262 | kW |
| Total Production | 2,298,963 | kWh/yr |

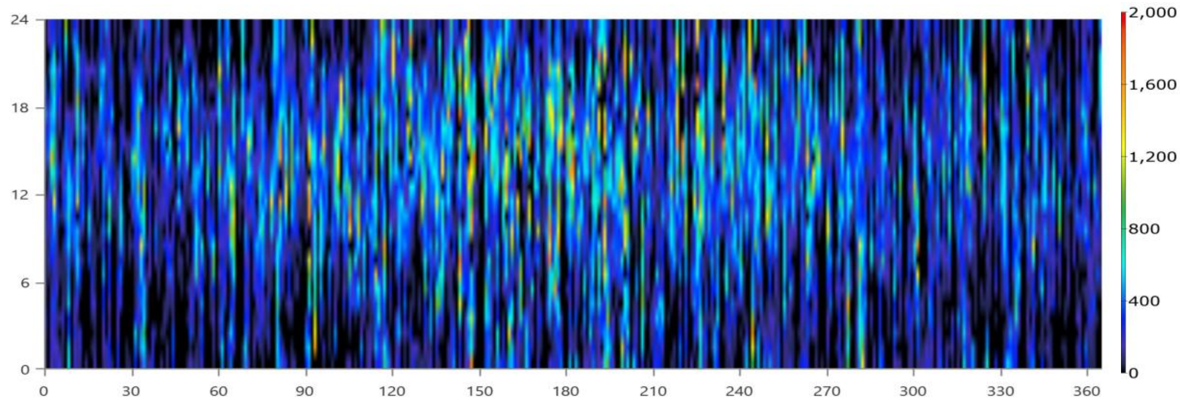



**Figure 4.19:-AWS HC 4.2kW Wind Turbine Output (kW)Scenario B**

### 4.5.7 Storage: Hoppecke 12 OPzS 1500

**Table 4.29Hoppecke 12 OPzS 1500 PropertiesScenario B**

| Quantity | Value | Units |
|---|---|---|
| **String Size** | 6.00 | batteries |
| **Batteries** | 1,800 | qty. |
| **Bus Voltage** | 12.0 | V |
| **Strings in Parallel** | 300 | strings |

**Table 4.30Hoppecke 12 OPzS 1500 Result DataScenario B**

| Quantity | Value | Units |
|---|---|---|
| **Average Energy Cost** | 0 | $/kWh |
| **Energy Out** | 243,373 | kWh/yr |
| **Energy In** | 280,023 | kWh/yr |
| **Storage Depletion** | 2,753 | kWh/yr |
| **Annual Throughput** | 262,436 | kWh/yr |
| **Losses** | 39,403 | kWh/yr |
| **Annual EFCs** | 40.6 | 1/yr |
| **Average Daily EFCs** | 0.111 | 1/day |

**Table 4.31Hoppecke 12 OPzS 1500 StatisticsScenario B**

| Quantity | Value | Units |
|---|---|---|
| **Autonomy** | 21.3 | hr |
| **Nominal Capacity** | 6,461 | kWh |
| **Storage Wear Cost** | 0.191 | $/kWh |
| **Usable Nominal Capacity** | 4,523 | kWh |
| **Expected Life** | 20.0 | yr |
| **Lifetime Throughput** | 5,248,715 | kWh |

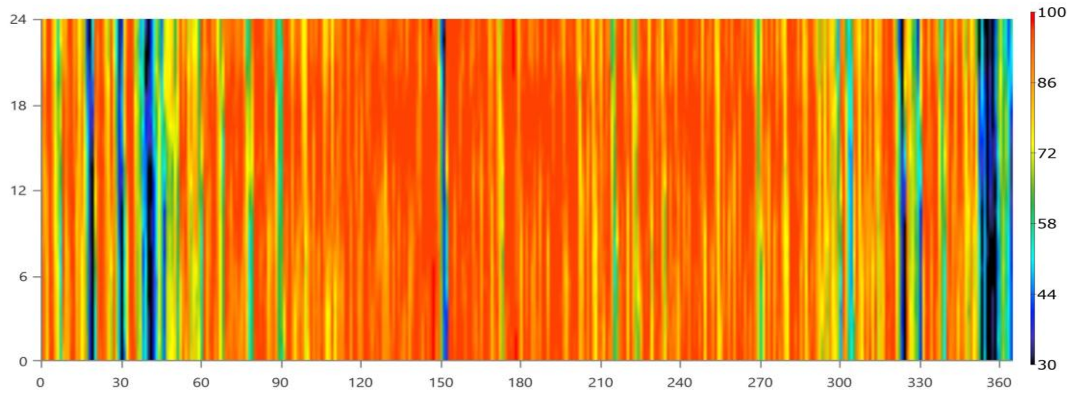



**Figure 4.20:-Hoppecke 12 OPzS 1500 State of Charge (%)**

### 4.5.8 Converter: Dynapower SPS - 100

**Table 4.32Dynapower SPS - 100 Electrical SummaryScenario B**

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 3,605 | hrs/yr |
| Energy In | 243,373 | kWh/yr |
| Energy Out | 234,855 | kWh/yr |
| Losses | 8,518 | kWh/yr |

**Table 4.33Dynapower SPS - 100 StatisticsScenario B**

| Quantity | Value | Units |
|---|---|---|
| Capacity | 332 | kW |
| Minimum Output | 0 | kW |
| Mean Output | 26.8 | kW |
| Capacity Factor | 8.08 | % |
| Maximum Output | 332 | kW |

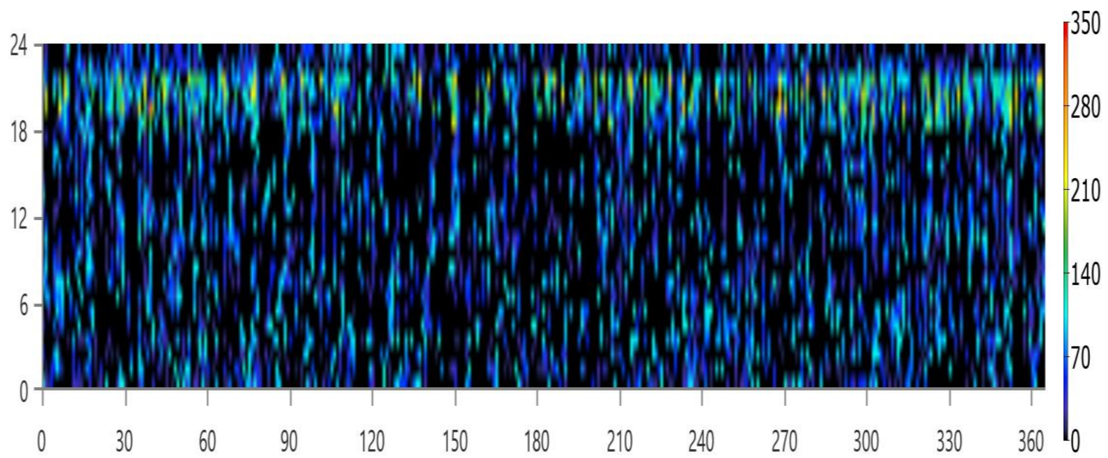



**Figure 4.21:-Dynapower SPS - 100 Inverter Output (kW)**

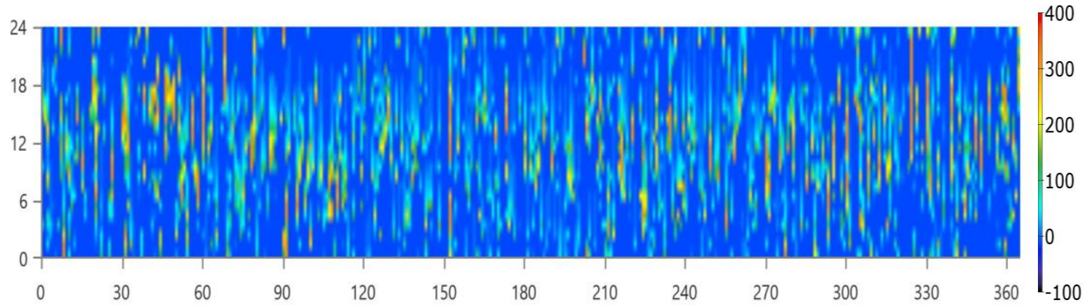



**Figure 4.22:-Dynapower SPS - 100 Rectifier Output (kW)**

### 4.5.9 Fuel Summary

**Table 4.34Biogas Consumption StatisticsScenario B**

| Quantity | Value | Units |
|---|---|---|
| Total feedstock consumed | 1,396 | tons |
| Avg feedstock per hour | 0.159 | tons/hour |
| Avg feedstock per day | 3.82 | tons/day |

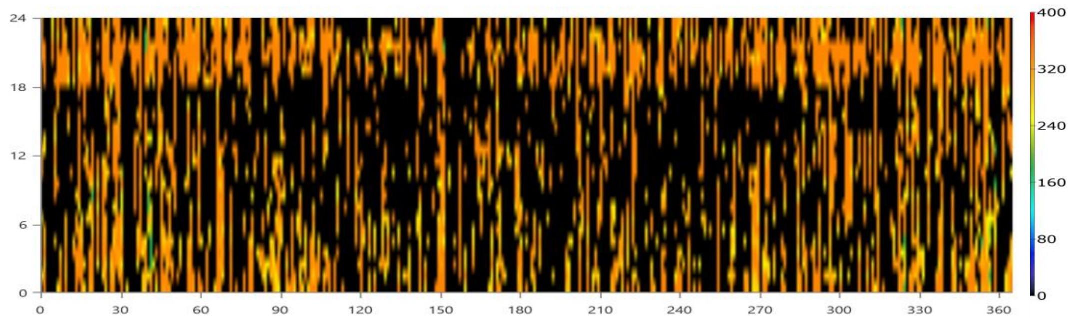



**Figure 4.23:-Biogas Consumption (kg/hr)**

**Table 4.35EmissionsScenario B**

| Pollutant | Quantity | Unit |
|---|---|---|
| Carbon Dioxide | 251 | kg/yr |
| Carbon Monoxide | 2.79 | kg/yr |
| Particulate Matter | 0 | kg/yr |
| Unburned Hydrocarbons | 0 | kg/yr |
| Sulfur Dioxide | 0 | kg/yr |
| Nitrogen Oxides | 1.74 | kg/yr |

**Table 4.36Renewable Summary**

| Capacity-based metrics | Value | Unit |
|---|---|---|
| Nominal renewable capacity divided by total nominal capacity | 100 | % |
| Usable renewable capacity divided by total capacity | 100 | % |
| **Energy-based metrics** | **Value** | **Unit** |
| Total renewable production divided by load | 148 | % |

| | | |
|---|---|---|
| **One minus total nonrenewable production divided by load** | 75.1 | % |
| **Total renewable production divided by generation** | 100 | % |
| **Peak values** | **Value** | **Unit** |
| **Renewable output divided by load (HOMER standard)** | 1,283 | % |
| **Renewable output divided by total generation** | 100 | % |
| **One minus nonrenewable output divided by total load** | 100 | % |

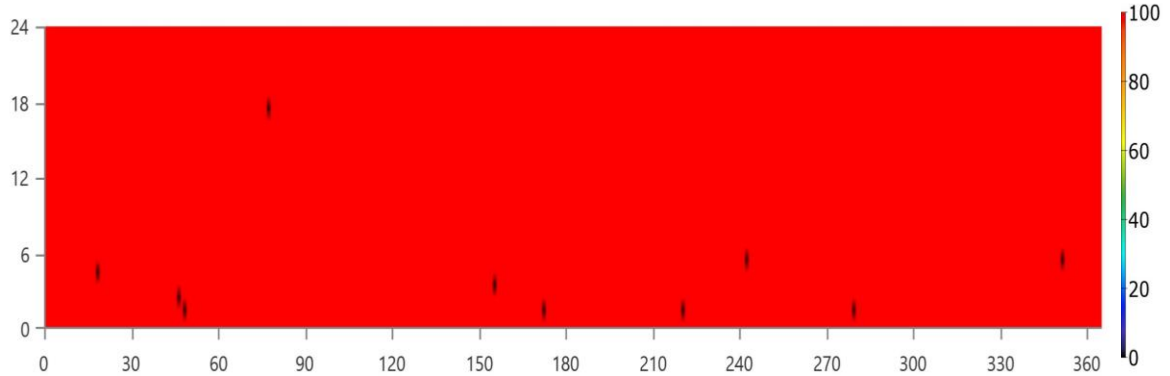



**Figure 4.24:-Instantaneous Renewable Output Percentage of Total Generation**

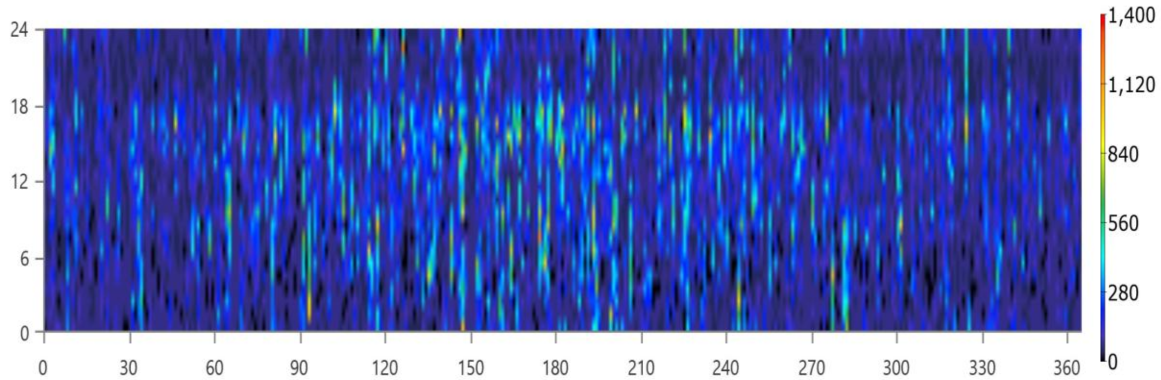



**Figure 4.25:-Instantaneous Renewable Output Percentage of Total Load**

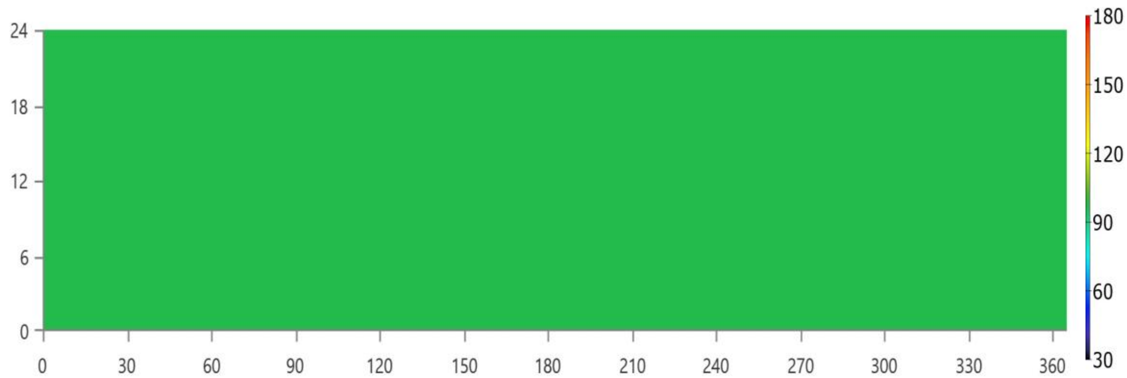



**Figure 4.26:-100% Minus Instantaneous Nonrenewable Output as Percentage**

### 4.5.10 Compare Economics

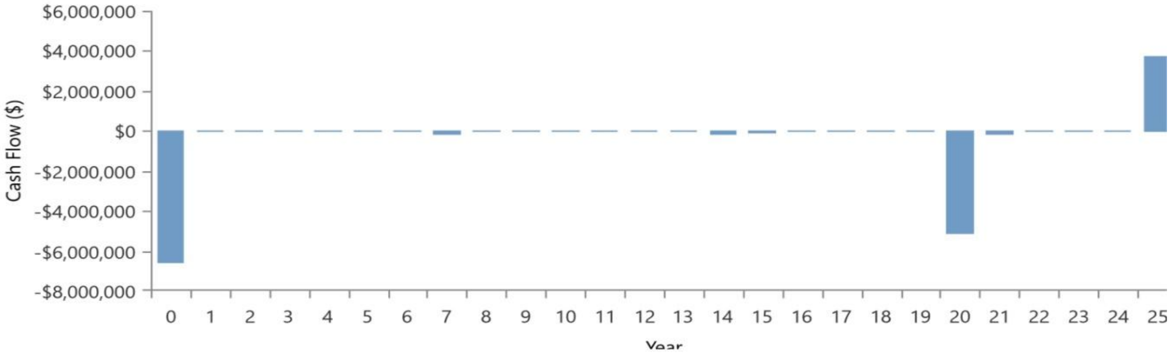
IRR (%):**N/A**

**Discounted payback (yr):N/A**

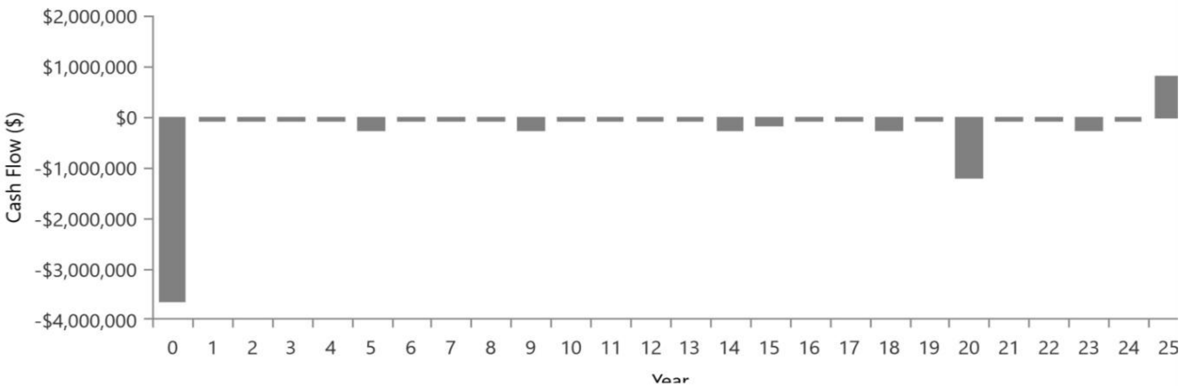
**Table 4.37Simple payback (yr):N/A**

| | **Base System** | **Proposed System** |
|---|---|---|
| **Net Present Cost** | $5.63M | $8.24M |
| **OPEX** | $151,342 | $126,268 |
| **CAPEX** | $3.67M | $6.61M |
| **LCOE (per kWh)** | $0.234 | $0.342 |
| **Fuel Consumption (L/yr)** | 2,369 | 1,396 |
| **CO2 Emitted (kg/yr)** | 427 | 251 |

### 4.5.11Proposed Annual Nominal Cash Flows




### 4.5.12 Base System Annual Nominal Cash Flows




### 4.5.13 Cumulative Discounted Cash Flows

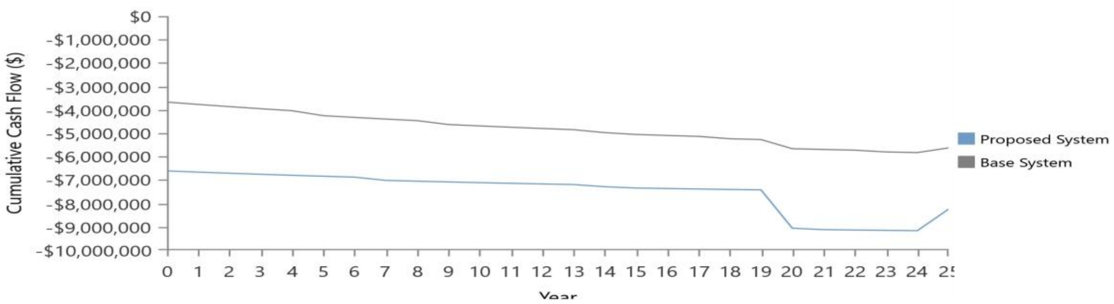


**Figure 4.27:-Demo Wind Biogas Micro grid proposed system**

### 4.5.14 Conclusion

In our recent study, we explored the feasibility of an off-grid hybrid power system that integrates wind energy and biogas to fulfill the energy needs of NijhumDwip, Bangladesh. Our primary objective was to evaluate both the technical and economic viability of this solution, especially given the unique challenges of a remote area. Implementing renewable energy sources can provide substantial advantages in sustainability, reliability, and cost-effectiveness. The key findings of our analysis highlight an impressive Levelized Cost of Energy (LCOE) of $0.342 per kWh.

### 4.6 Scenario C Biogas-Solar PV Micro grid system

#### 4.6.1 Introduction

A microgrid system powered by biogas and solar PV is an effective and sustainable way to supply electricity to the community of NijhumDwip. This hybrid approach utilizes biogas for consistent baseload power and solar PV to harness energy during the day, ensuring a dependable energy supply for the island. The microgrid is designed to meet a daily demand of 5,102 kWh, with a peak capacity of 527 kW. In this setup, the specified generation sources will effectively address the electrical load requirements.

#### 4.6.2System Architecture

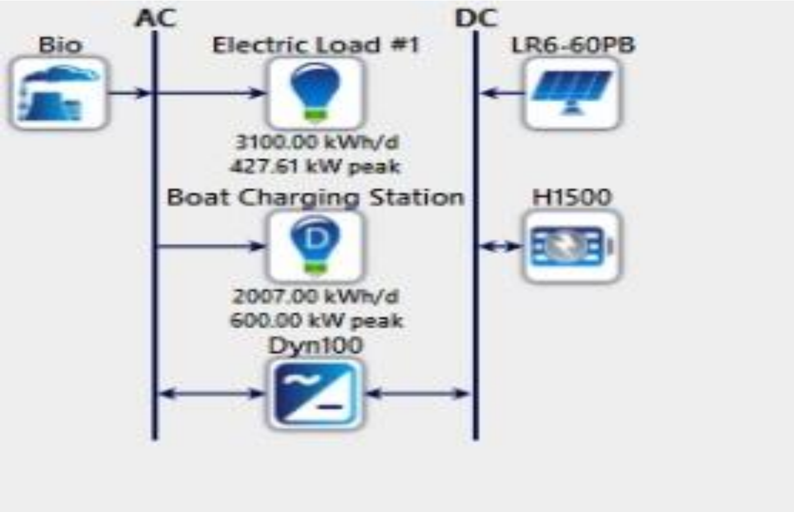



**Figure 4.28:- Scenario C  Biogas-Solar PV Micro grid system**

**Table 4.38 system configuration for scenario C**

| Component | Name | Size | Unit |
|---|---|---|---|
| **Generator** | Generic Biogas Genset | 190 | kW |
| **PV** | LONGi Solar LR6-60PB | 2,051 | kW |
| **Storage** | Hoppecke 12 OPzS 1500 | 208 | strings |
| **System converter** | Dynapower SPS - 100 | 343 | kW |
| **Dispatch strategy** | HOMER Load Following | | |

### 4.6.3 Cost summary

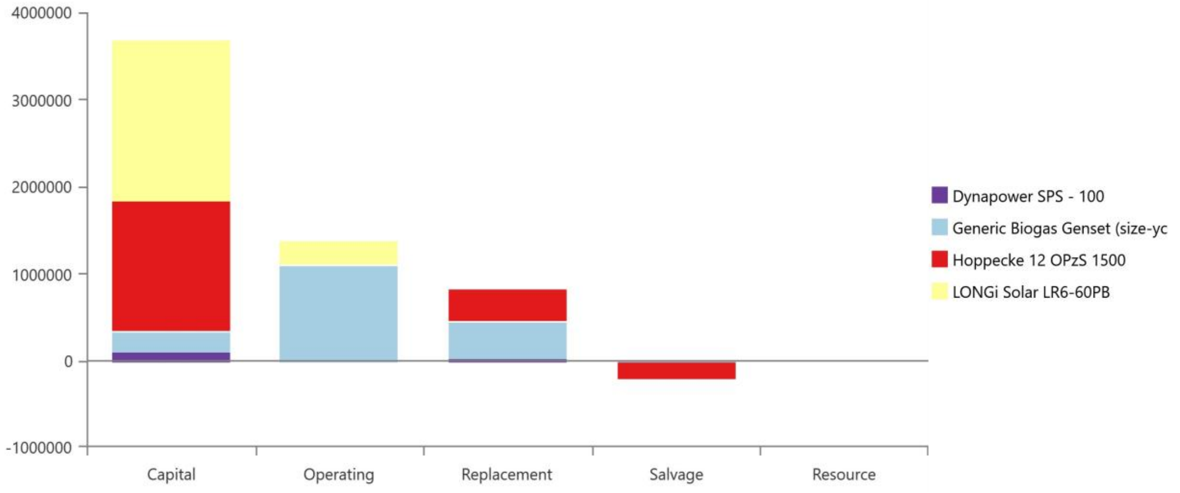



**Figure 4.29:- cost summary for Scenario C**

**Table 4.39Net Present Costsfor scenario C**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **Dynapower SPS - 100** | $99,571 | $0.00 | $33,505 | -$6,306 | $0.00 | $126,771 |
| **Generic Biogas Genset** | $228,000 | $1.09M | $422,635 | -$17,563 | $0.00 | $1.73M |
| **Hoppecke 12 OPzS 1500** | $1.50M | $8,067 | $358,084 | -$201,804 | $0.00 | $1.66M |
| **LONGi Solar LR6-60PB** | $1.85M | $265,110 | $0.00 | $0.00 | $0.00 | $2.11M |
| **System** | $3.67M | $1.37M | $814,225 | -$225,673 | $0.00 | $5.63M |

**Table 4.40Annualized Costsfor scenario C**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **Dynapower SPS - 100** | $7,702 | $0.00 | $2,592 | -$487.80 | $0.00 | $9,806 |
| **Generic Biogas Genset** | $17,637 | $84,683 | $32,693 | -$1,359 | $0.00 | $133,654 |
| **Hoppecke 12 OPzS 1500** | $115,846 | $624.00 | $27,699 | -$15,610 | $0.00 | $128,559 |
| **LONGi Solar LR6-60PB** | $142,770 | $20,507 | $0.00 | $0.00 | $0.00 | $163,278 |
| **System** | $283,955 | $105,814 | $62,984 | -$17,457 | $0.00 | $435,297 |

### 4.6.4 Cash Flow

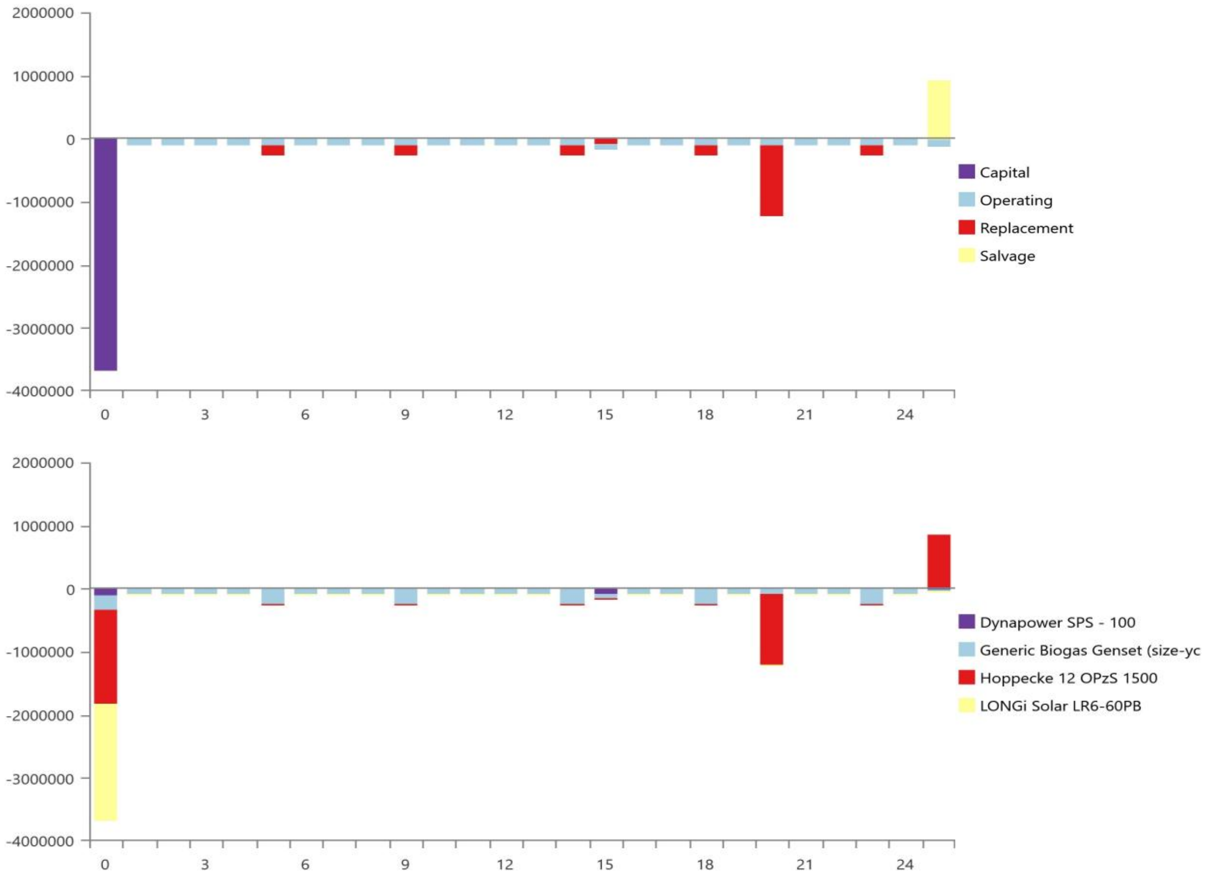



**Figure 4.30:- cash flow forScenario C**

### 4.6.5 Electric Consumption

This microgrid requires 5102 kWh/day and has a peak of 527 kW. In the proposed system, the following generation sources serve the electrical load.

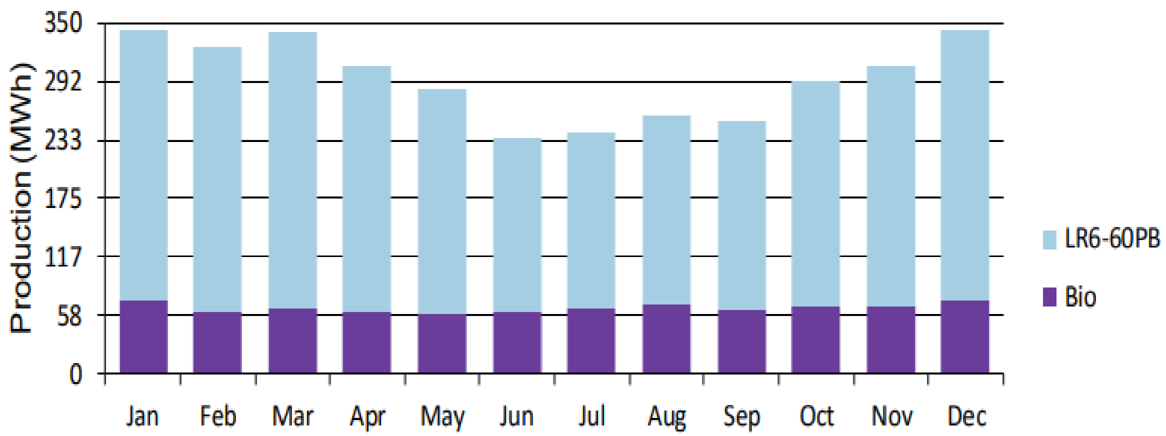



**Figure 4.31:- Solar + biogas Electric Consumption scenario**

**Table 4.41Excess and Unmetfor scenario C**

| Quantity | Value | kWh/yr |
|---|---|---|
| Excess Electricity | 1,569,770 | kWh/yr |
| Unmet Electric Load | 1,585 | |
| Capacity Shortage | 1,838 | kWh/yr |

**Table 4.42Production Summaryfor scenario C**

| Component | Production (kWh/yr) | Percent |
|---|---|---|
| LONGi Solar LR6-60PB | 2,731,105 | 77.6 |
| Generic Biogas Genset | 786,707 | 22.4 |
| Total | 3,517,812 | 100 |

**Table 4.43Consumption Summaryfor scenario C**

| Component | Consumption (kWh/yr) | Percent |
|---|---|---|
| AC Primary Load | 1,130,982 | 60.7 |
| DC Primary Load | 0 | 0 |
| Deferrable Load | 731,488 | 39.3 |
| Total | 1,862,470 | 100 |

### 4.6.6 Generator: Generic Biogas Genset (Biogas)

**Table 4.44Generic Biogas GensetElectrical Summaryfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Mean Electrical Output | 177 | kW |
| Electrical Production | 786,707 | kWh/yr |
| Maximum Electrical Output | 190 | kW |
| Minimum Electrical Output | 95.0 | kW |

**Table 4.45Generic Biogas GensetFuel Summaryfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Fuel Consumption | 2,369 | tons/yr |
| Fuel Energy Input | 2,533,203 | kWh/yr |
| Specific Fuel Consumption | 2.11 | kg/kWh |
| Mean Electrical Efficiency | 31.1 | % |

**Table 4.46Generic Biogas Genset Statisticsfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 4,457 | hrs/yr |
| Operational Life | 4.49 | yr |
| Number of Starts | 560 | starts/yr |
| Capacity Factor | 47.3 | % |
| Marginal Generation Cost | 0 | $/kWh |
| Fixed Generation Cost | 27.6 | $/hr |

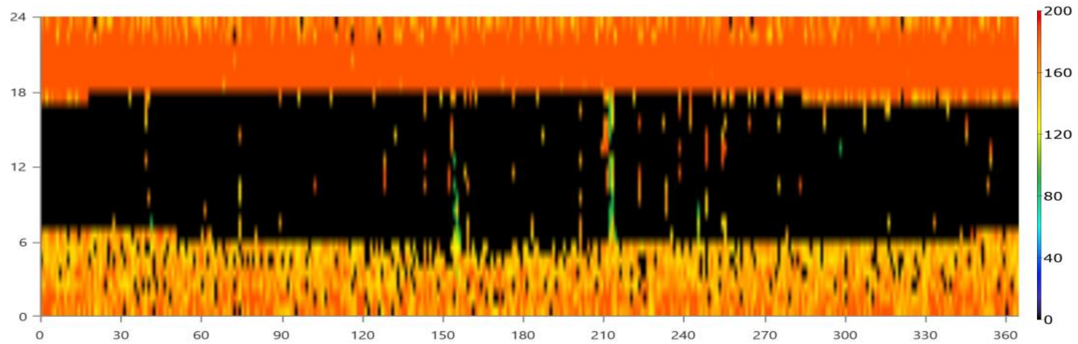



**Figure 4.32:-Generic Biogas Genset (size-your-own) Output (kW)**

### 4.6.7 PV: LONGi Solar LR6-60PB

**Table 4.47LONGi Solar LR6-60PB Electrical Summaryfor scenario C**

| Quantity | Value | kW |
|---|---|---|
| Minimum Output | 0 | kW |
| Maximum Output | 1,708 | |
| PV Penetration | 241 | % |
| Levelized Cost | 0.0598 | $/kWh |
| Clipped production | 0 | kWh |
| Hours of Operation | 4,370 | hrs/yr |

**Table 4.48LONGi Solar LR6-60PB Statisticsfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Rated Capacity | 2,051 | kW |
| Mean Output | 7,482 | kWh/d |
| Capacity Factor | 15.2 | % |
| Mean Output | 312 | kW |
| Total Production | 2,731,105 | kWh/yr |

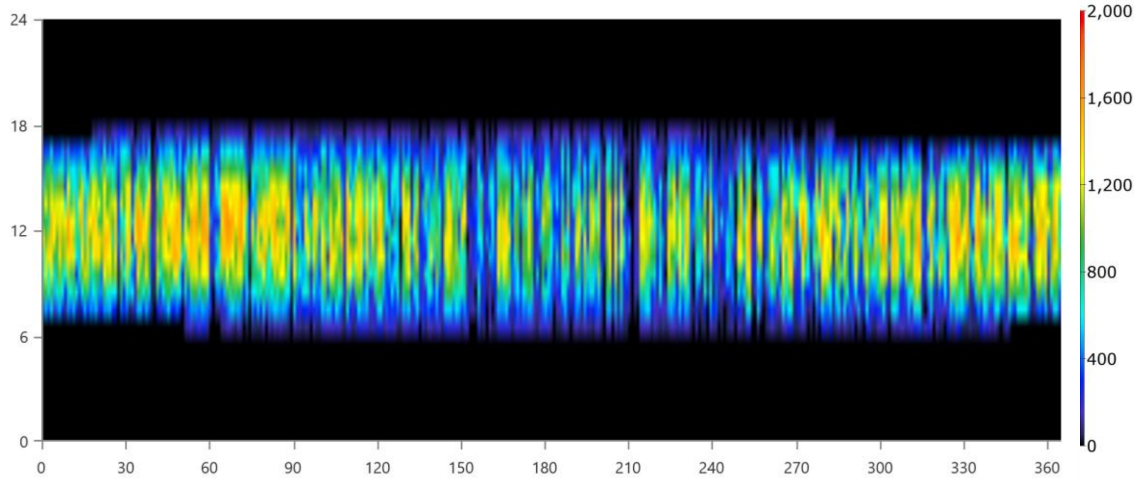



**Figure 4.33:-LONGi Solar LR6-60PB**

### 4.6.8 Storage: Hoppecke 12 OPzS 1500

**Table 4.49Hoppecke 12 OPzS 1500 Propertiesfor scenario C**

| Quantity | Value | qty. |
|---|---|---|
| Batteries | 1,248 | batteries |
| String Size | 6.00 | |
| Bus Voltage | 12.0 | V |
| Strings in Parallel | 208 | strings |

**Table 4.50Hoppecke 12 OPzS 1500 Result Datafor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Average Energy Cost | 0 | $/kWh |
| Energy In | 337,892 | kWh/yr |
| Storage Depletion | 809 | kWh/yr |
| Energy Out | 291,337 | kWh/yr |
| Losses | 47,364 | kWh/yr |
| Annual EFCs | 70.1 | 1/yr |
| Annual Throughput | 314,157 | kWh/yr |
| Average Daily EFCs | 0.192 | 1/day |

**Table 4.51Hoppecke 12 OPzS 1500 Statisticsfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Autonomy | 14.7 | hr |
| Nominal Capacity | 4,480 | kWh |
| Storage Wear Cost | 0.191 | $/kWh |
| Usable Nominal Capacity | 3,136 | kWh |
| Expected Life | 20.0 | yr |
| Lifetime Throughput | 6,283,143 | kWh |

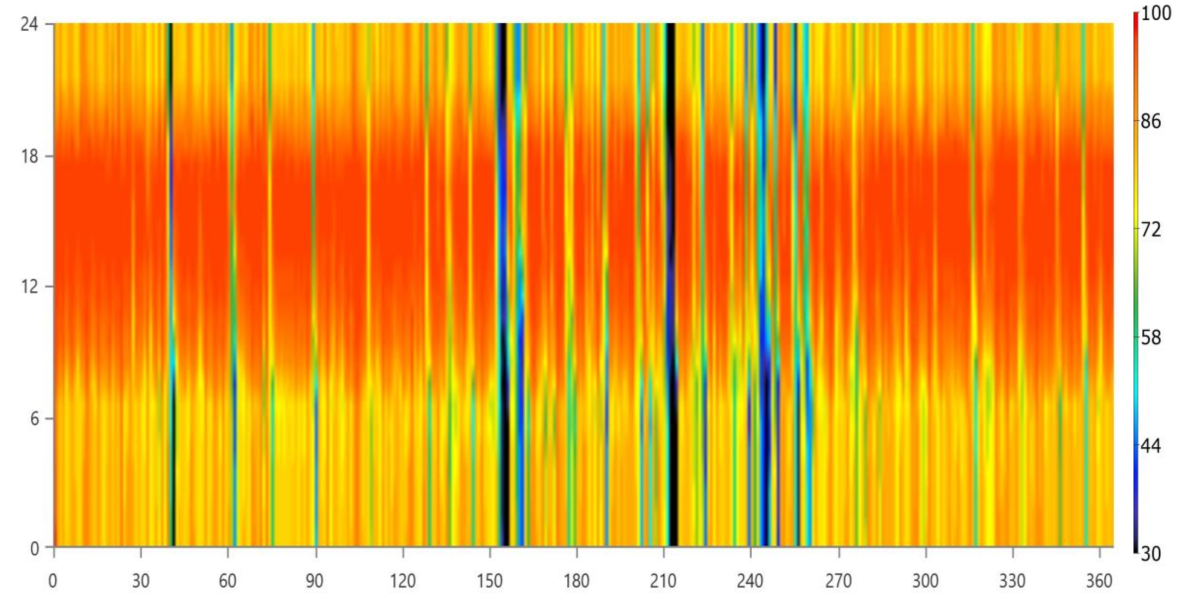



**Figure 4.34:-Hoppecke 12 OPzS 1500 State of Charge (%)**

### 4.6.9 Converter: Dynapower SPS - 100

**Table 4.52Dynapower SPS - 100 Electrical Summaryfor scenario C**

| Quantity | Value | hrs/yr |
|---|---|---|
| Hours of Operation | 6,599 | kWh/yr |
| Energy Out | 1,075,763 | |
| Losses | 39,017 | kWh/yr |
| Energy In | 1,114,780 | kWh/yr |

**Table 4.53Dynapower SPS - 100 Statisticsfor scenario C**

| Quantity | Value | Units |
|---|---|---|
| Capacity | 343 | kW |
| Minimum Output | 0 | kW |
| Mean Output | 123 | kW |
| Capacity Factor | 35.8 | % |
| Maximum Output | 337 | kW |

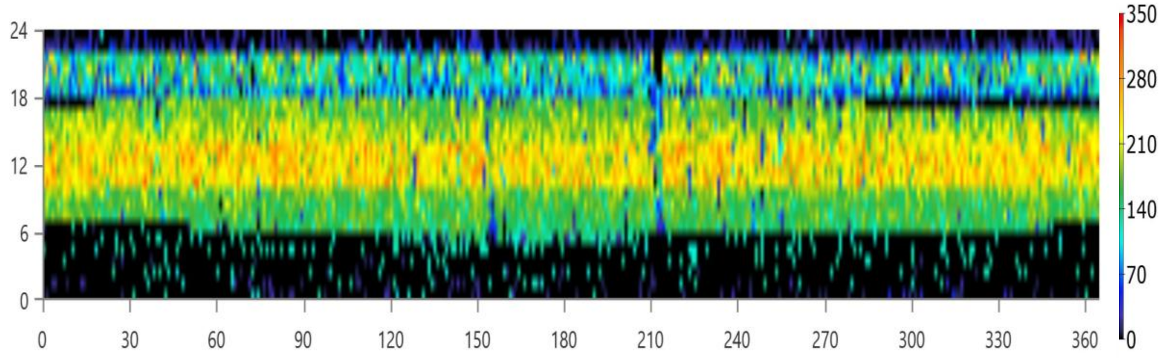



**Figure 4.35:-Dynapower SPS - 100 Inverter Output (kW)**

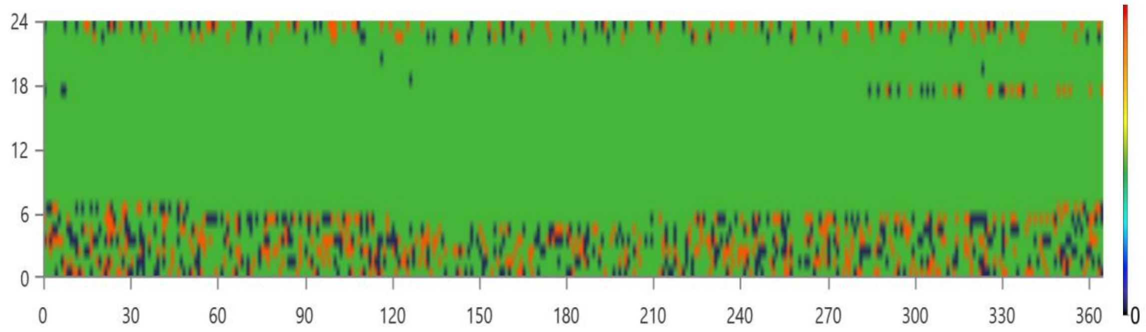



**Figure 4.36:-Dynapower SPS - 100 Rectifier Output (kW)**

### 4.6.10 Fuel Summary

**Table 4.54Biogas Consumption Statisticsfor scenario C**

| Quantity | Value | tons tons/day |
|---|---|---|
| Total feedstock consumed | 2,369 | |
| Avg feedstock per day | 6.49 | |
| Avg feedstock per hour | 0.270 | tons/hour |

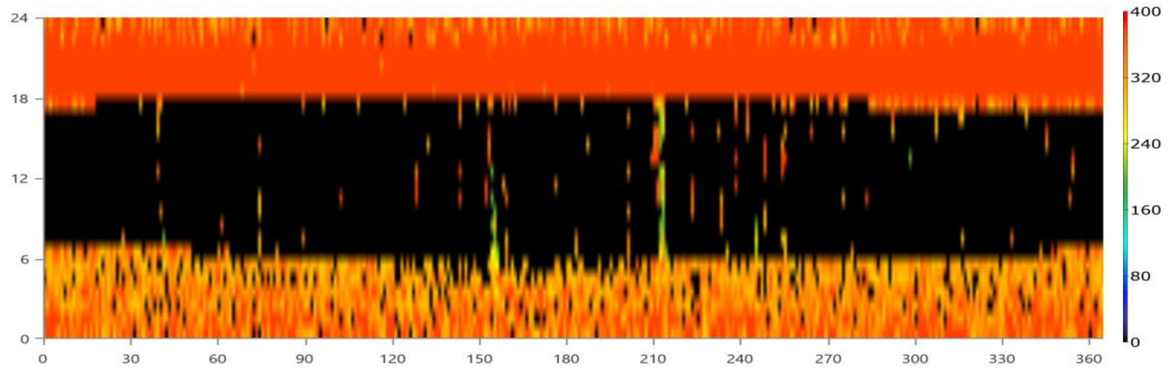



**Figure 4.37:-Biogas Consumption (kg/hr)**

**Table 4.55Emissionsfor scenario C**

| Pollutant | Quantity | Unit |
|---|---|---|
| **Carbon Dioxide** | 427 | kg/yr |
| **Unburned Hydrocarbons** | 0 | kg/yr |
| **Carbon Monoxide** | 4.74 | kg/yr |
| **Sulfur Dioxide** | 0 | kg/yr |
| **Particulate Matter** | 0 | kg/yr |
| **Nitrogen Oxides** | 2.96 | kg/yr |

**Table 4.56Renewable Summaryfor scenario C**

| Capacity-based metrics | Value | Unit |
|---|---|---|
| **Usable renewable capacity divided by total capacity** | 100 | % |
| **Nominal renewable capacity divided by total nominal capacity** | 100 | % |
| **Energy-based metrics** | **Value** | **Unit** |
| **Total renewable production divided by load** | 189 | % |
| **One minus total nonrenewable production divided by load** | 57.8 | % |
| **Total renewable production divided by generation** | 100 | % |
| **Peak values** | **Value** | **Unit** |
| **Renewable output divided by load (HOMER standard)** | 1,212 | % |
| **One minus nonrenewable output divided by total load** | 100 | % |
| **Renewable output divided by total generation** | 100 | % |

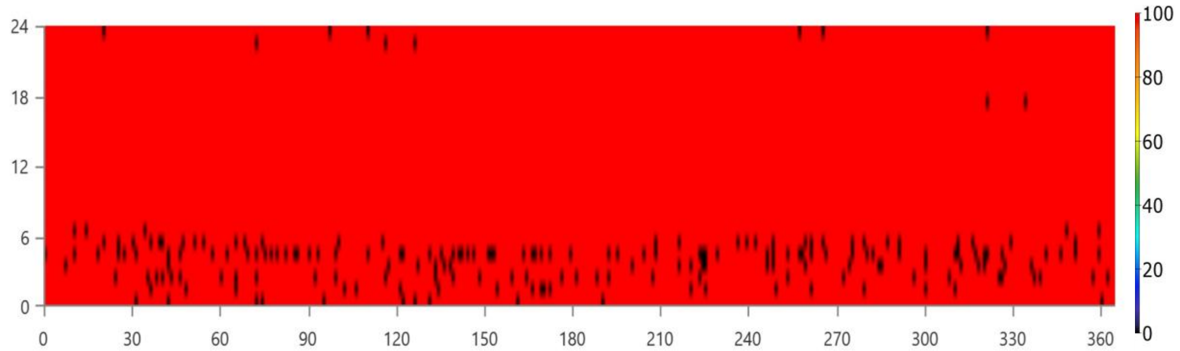



**Figure 4.38:-Instantaneous Renewable Output Percentage of Total Generation**

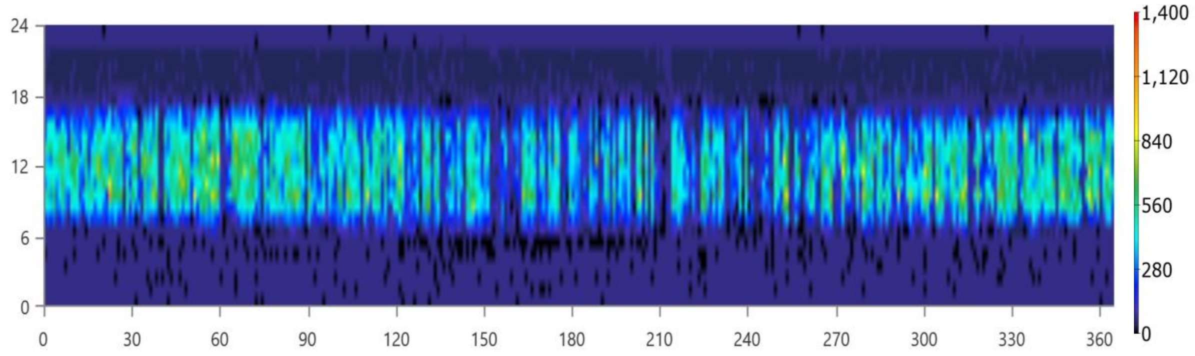



**Figure 4.39:-Instantaneous Renewable Output Percentage of Total Load**

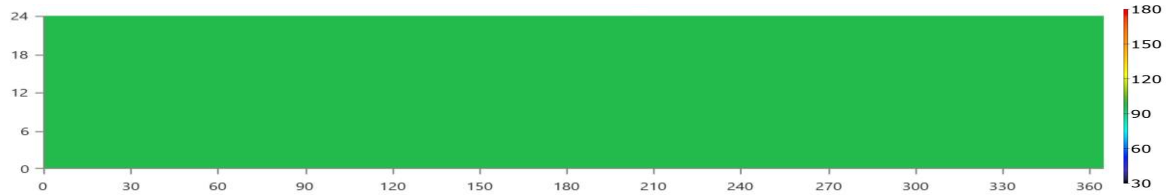



**Figure 4.40:-100% Minus Instantaneous Nonrenewable Output ofTotal Load**

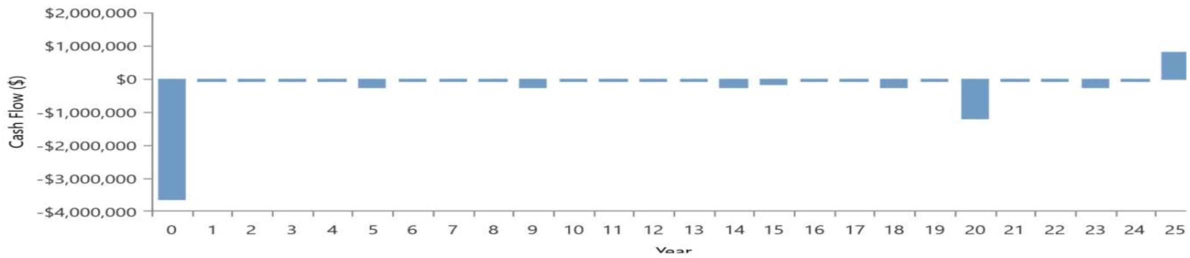
### 4.6.11 Compare Economics

**Discounted payback (yr)**:**N/A**

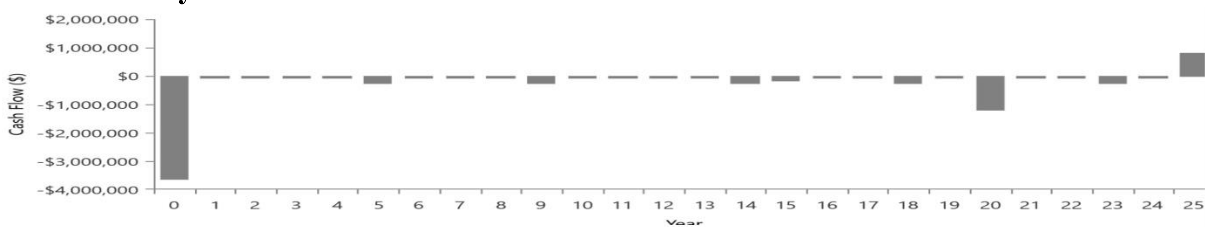
**Table 4.57Simple payback (yr):N/A**

| | **Base System** | **Proposed System** |
|---|---|---|
| **Net Present Cost** | $5.63M | $5.63M |
| **CAPEX** | $3.67M | $3.67M |
| **LCOE (per kWh)** | $0.234 | $0.234 |
| **OPEX** | $151,342 | $151,342 |
| **Fuel Consumption (L/yr)** | 2,369 | 2,369 |
| **CO2 Emitted (kg/yr)** | 427 | 427 |

### 4.6.12 Proposed Annual Nominal Cash Flows




### 4.6.13 Base System Annual Nominal Cash Flows



### 4.6.14 Cumulative Discounted Cash Flows

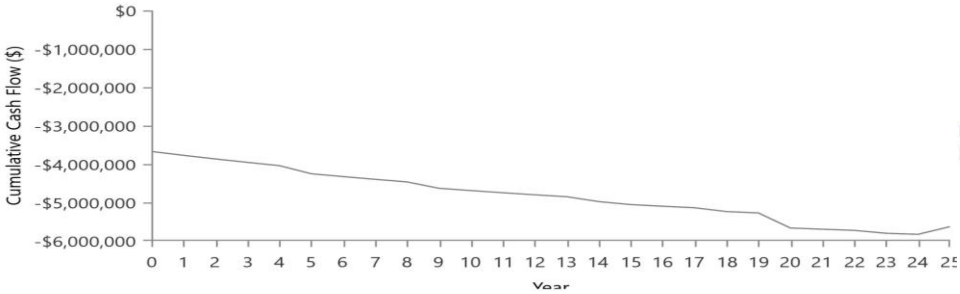




**Figure 4.41:- Demo solar Biogas Microgrid system**

### 4.6.15 Conclusion

The biogas-solar hybrid off-grid system, with a Levelized Cost of Energy (LCOE) of $0.234 per kWh, presents an economically sound, environmentally friendly, and dependable energy solution for remote regions like NijhumDwip, Bangladesh. By harnessing the advantages of solar energy during daylight hours and utilizing biogas for consistent baseload power, this system delivers a clean and affordable energy option.

### 4.7 Scenario D Wind- Biogas-Solar PV Micro grid system

#### 4.7.1 Introduction

A Wind-Biogas-Solar PV Microgrid System for Nijhumdwip presents an exciting opportunity for a resilient and sustainable energy future on the island. Not only will it enhance energy access, but it will also promote environmental sustainability and boost economic growth. We propose the addition of 449 kW of wind generation capacity, which could lower operating costs to $116,216 per year. With a payback period of just 0.717 years and an impressive internal rate of return (IRR) of 148%, this investment stands to benefit the community significantly.

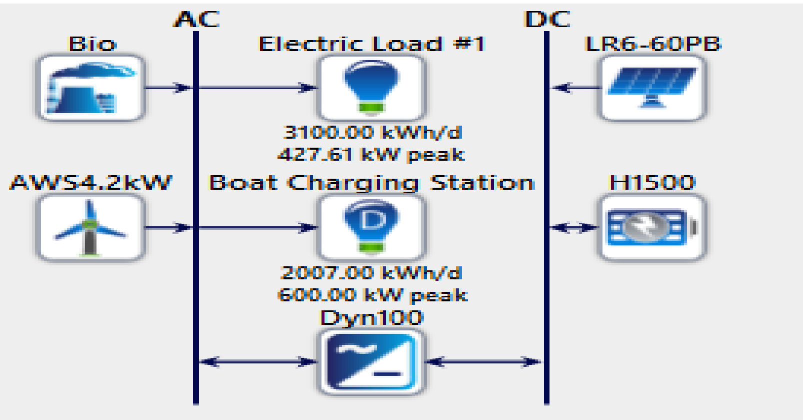



**Fig. 4.42:-Scenario D Wind- Biogas-Solar PV Micro grid system**

**Table 4.58 System Configurationfor Scenario D**

| Component | Name | Size | Unit |
|---|---|---|---|
| **Generator** | Generic Biogas Genset | 175 | kW |
| **PV** | LONGi Solar LR6-60PB | 831 | kW |
| **Wind turbine** | AWS HC 4.2kW Wind Turbine | 107 | ea. |
| **System converter** | Dynapower SPS - 100 | 306 | kW |
| **Storage** | Hoppecke 12 OPzS 1500 | 190 | strings |

#### 4.7.2 Cost Summary

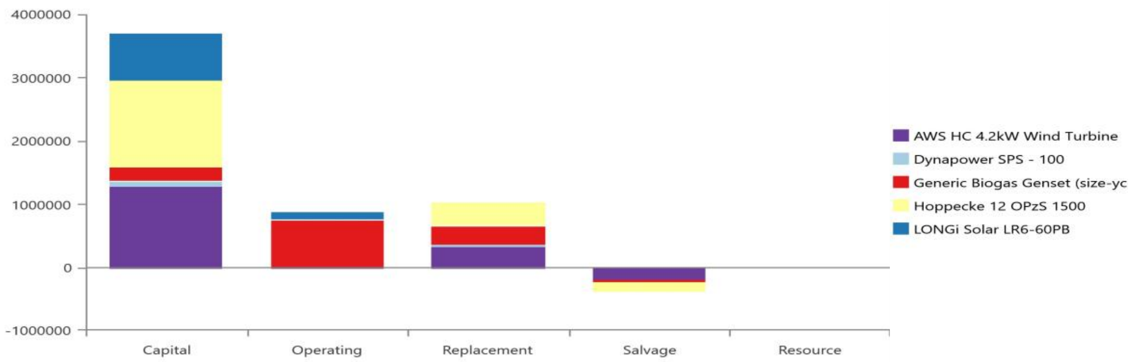


**Figure 4.43:- cost summary**

**Table 4.59Net percent costScenario D**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $1.28M | $13,832 | $341,124 | -$192,245 | $0.00 | $1.45M |
| **Dynapower SPS - 100** | $88,698 | $0.00 | $29,846 | -$5,617 | $0.00 | $112,926 |
| **Generic Biogas Genset** | $210,000 | $740,908 | $283,709 | -$34,193 | $0.00 | $1.20M |
| **Hoppecke 12 OPzS 1500** | $1.37M | $7,369 | $363,417 | -$153,169 | $0.00 | $1.59M |
| **LONGi Solar LR6-60PB** | $747,772 | $107,409 | $0.00 | $0.00 | $0.00 | $855,182 |
| **System** | $3.70M | $869,519 | $1.02M | -$385,225 | $0.00 | $5.20M |

**Table 4.60Annualized CostsScenario D**

| Name | Capital | Operating | Replacement | Salvage | Resource | Total |
|---|---|---|---|---|---|---|
| **AWS HC 4.2kW Wind Turbine** | $99,323 | $1,070 | $26,387 | -$14,871 | $0.00 | $111,909 |
| **Dynapower SPS - 100** | $6,861 | $0.00 | $2,309 | -$434.53 | $0.00 | $8,735 |
| **Generic Biogas Genset (size-your-own)** | $16,244 | $57,313 | $21,946 | -$2,645 | $0.00 | $92,858 |
| **Hoppecke 12 OPzS 1500** | $105,821 | $570.00 | $28,112 | -$11,848 | $0.00 | $122,654 |
| **LONGi Solar LR6-60PB** | $57,843 | $8,309 | $0.00 | $0.00 | $0.00 | $66,152 |
| **System** | $286,093 | $67,261 | $78,754 | -$29,799 | $0.00 | $402,309 |

### 4.7.3 Cash flow

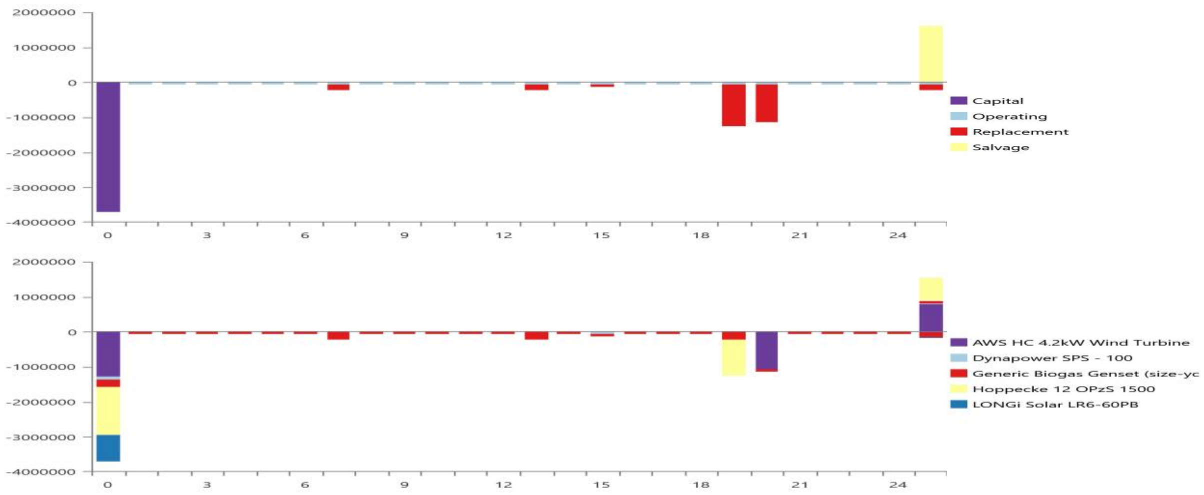



**Figure 4.44:- Cash flow Scenario D**

**Table 4.61 Electrical summaryScenario**

| Quantity | Value | Units |
|---|---|---|
| **Excess Electricity** | 413,129 | kWh/yr |
| **Capacity Shortage** | 1,835 | kWh/yr |
| **Unmet Electric Load** | 1,510 | kWh/yr |

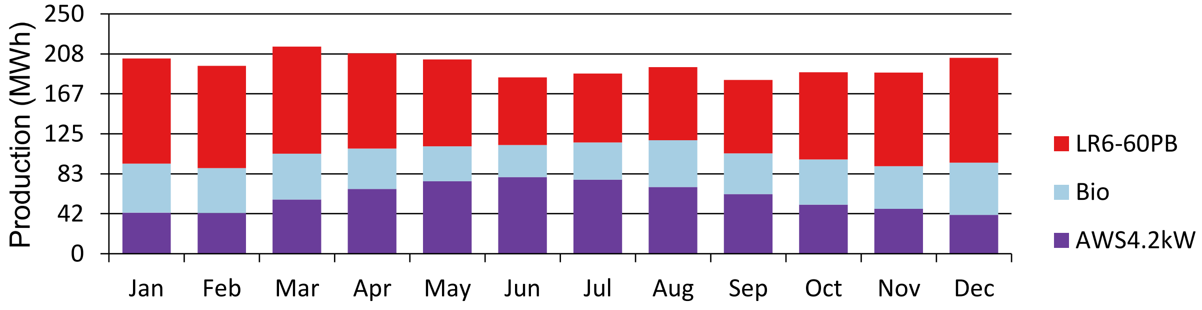



**Figure 4.45:- Production Summa**

**Table 4.62 Production Summary for Scenario D**

| Component | Production (kWh/yr) | Percent |
|---|---|---|

| | | |
|---|---|---|
| **LONGi Solar LR6-60PB** | 1,106,507 | 47.1 |
| **AWS HC 4.2kW Wind Turbine** | 710,951 | 30.3 |
| **Generic Biogas Genset** | 532,058 | 22.6 |
| **Total** | 2,349,516 | 100 |

**Table 4.63Consumption Summaryfor Scenario D**

| **Component** | **Consumption (kWh/yr)** | **Percent** |
|---|---|---|
| **AC Primary Load** | 1,131,192 | 60.7 |
| **Deferrable Load** | 731,354 | 39.3 |
| **DC Primary Load** | 0 | 0 |
| **Total** | 1,862,545 | 100 |

### 4.7.4 Generator: Generic Biogas Genset (Biogas)

**Table 4.64Generic Biogas GensetElectrical Summaryfor Scenario D**

| **Quantity** | **Value** | **Units** |
|---|---|---|
| **Electrical Production** | 532,058 | kWh/yr |
| **Mean Electrical Output** | 162 | kW |
| **Maximum Electrical Output** | 175 | kW |
| **Minimum Electrical Output** | 87.5 | kW |

**Table 4.65Generic Biogas Genset Fuel Summaryfor Scenario D**

| **Quantity** | **Value** | **Units** |
|---|---|---|
| **Fuel Consumption** | 1,602 | tons/yr |
| **Fuel Energy Input** | 1,713,293 | kWh/yr |
| **Mean Electrical Efficiency** | 31.1 | % |
| **Specific Fuel Consumption** | 2.11 | kg/kWh |

**Table 4.66Generic Biogas Genset Statisticsfor Scenario D**

| **Quantity** | **Value** | **Units** |
|---|---|---|
| **Hours of Operation** | 3,275 | hrs/yr |
| **Operational Life** | 6.11 | yr |
| **Number of Starts** | 689 | starts/yr |
| **Capacity Factor** | 34.7 | % |
| **Marginal Generation Cost** | 0 | $/kWh |
| **Fixed Generation Cost** | 25.4 | $/hr |

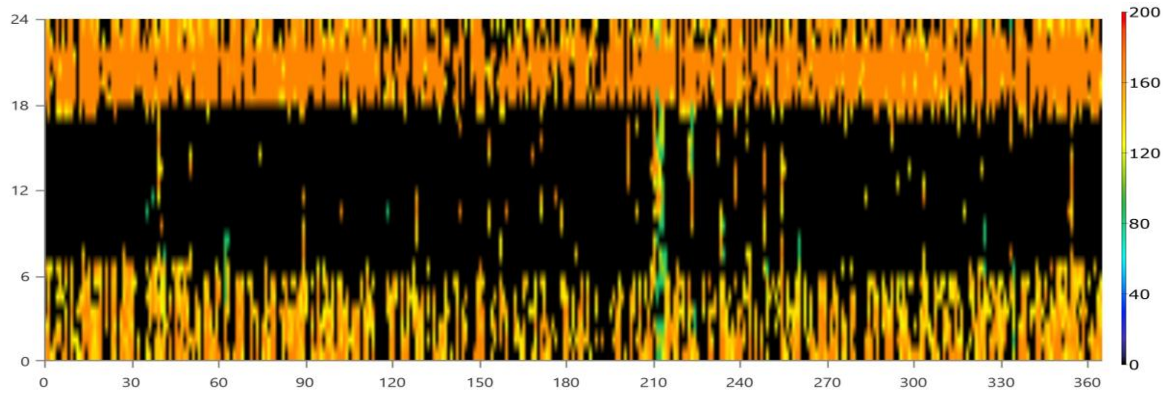



**Figure 4.46:-Generic Biogas Genset (size-your-own) Output (kW)for Scenario D**

### 4.7.5 PV: LONGi Solar LR6-60PBfor Scenario D

**Table 4.67LONGi Solar LR6-60PB Electrical Summaryfor Scenario D**

| Quantity | Value | Units |
|---|---|---|
| **Minimum Output** | 0 | kW |
| **PV Penetration** | 97.8 | % |
| **Maximum Output** | 692 | kW |
| **Levelized Cost** | 0.0598 | $/kWh |
| **Hours of Operation** | 4,370 | hrs/yr |
| **Clipped production** | 0 | kWh |

**Table 4.68LONGi Solar LR6-60PB Statisticsfor Scenario D**

| Quantity | Value | Units |
|---|---|---|
| **Rated Capacity** | 831 | kW |
| **Mean Output** | 3,032 | kWh/d |
| **Mean Output** | 126 | kW |
| **Capacity Factor** | 15.2 | % |
| **Total Production** | 1,106,507 | kWh/yr |

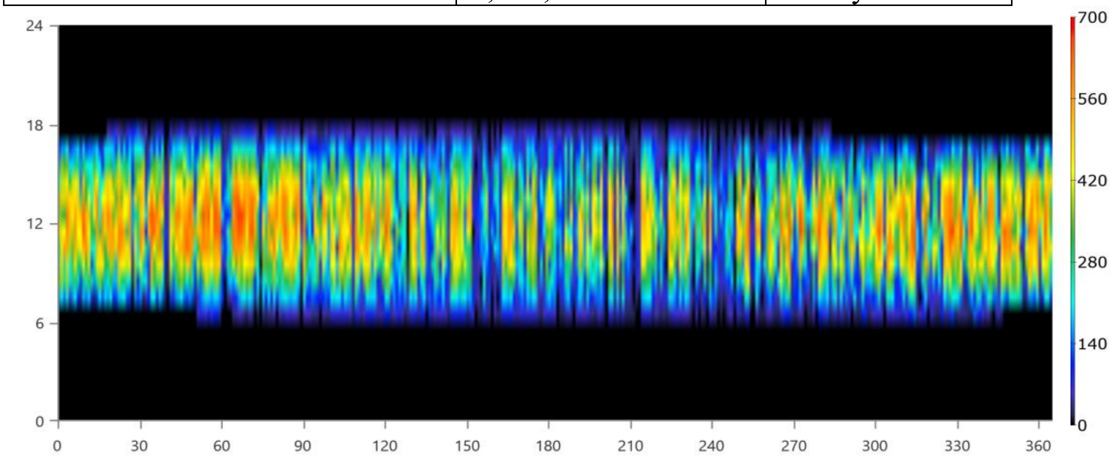



**Figure 4.47:-LONGi Solar LR6-60PB Output (kW)for Scenario D**

### 4.7.6 Wind Turbine: AWS HC 4.2kW Wind Turbinefor Scenario D

Table 4.69AWS HC 4.2kW Wind Turbine Electrical Summaryfor Scenario D

| Quantity | Value | Units |
|---|---|---|
| Minimum Output | 0 | kW |
| Wind Penetration | 62.8 | % |
| Maximum Output | 584 | kW |
| Levelized Cost | 0.157 | $/kWh |
| Hours of Operation | 7,357 | hrs/yr |

Table 4.70AWS HC 4.2kW Wind Turbine Statisticsfor Scenario D

| Quantity | Value | Units |
|---|---|---|
| Total Rated Capacity | 449 | kW |
| Capacity Factor | 18.1 | % |
| Mean Output | 81.2 | kW |
| Total Production | 710,951 | kWh/yr |

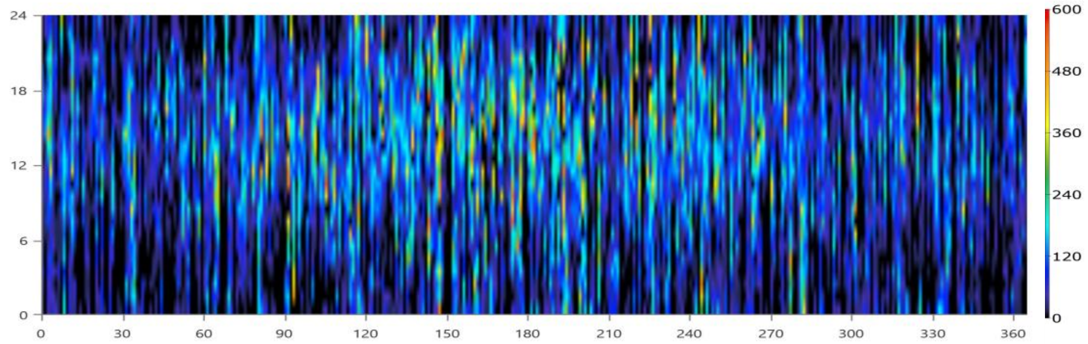



Figure 4.48:-AWS HC 4.2kW Wind Turbine Output (kW)for Scenario D

### 4.7.7 Storage: Hoppecke 12 OPzS 1500

Table 4.71Hoppecke 12 OPzS 1500 Propertiesfor Scenario D

| Quantity | Value | Units |
|---|---|---|
| Batteries | 1,140 | qty. |
| Strings in Parallel | 190 | strings |
| String Size | 6.00 | batteries |
| Bus Voltage | 12.0 | V |

Table 4.72Hoppecke 12 OPzS 1500 Result Datafor Scenario D

| Quantity | Value | Units |
|---|---|---|
| Average Energy Cost | 0 | $/kWh |
| Energy In | 343,441 | kWh/yr |
| Storage Depletion | 468 | kWh/yr |
| Energy Out | 295,794 | kWh/yr |
| Losses | 48,116 | kWh/yr |
| Annual EFCs | 77.9 | 1/yr |
| Annual Throughput | 318,962 | kWh/yr |

| Average Daily EFCs | 0.214 | 1/day |
|---|---|---|

**Table 4.73Hoppecke 12 OPzS 1500 Statisticsfor Scenario D**

| Quantity | Value | Units |
|---|---|---|
| Autonomy | 13.5 | hr |
| Storage Wear Cost | 0.191 | $/kWh |
| Nominal Capacity | 4,092 | kWh |
| Usable Nominal Capacity | 2,865 | kWh |
| Expected Life | 18.2 | yr |
| Lifetime Throughput | 5,791,656 | kWh |

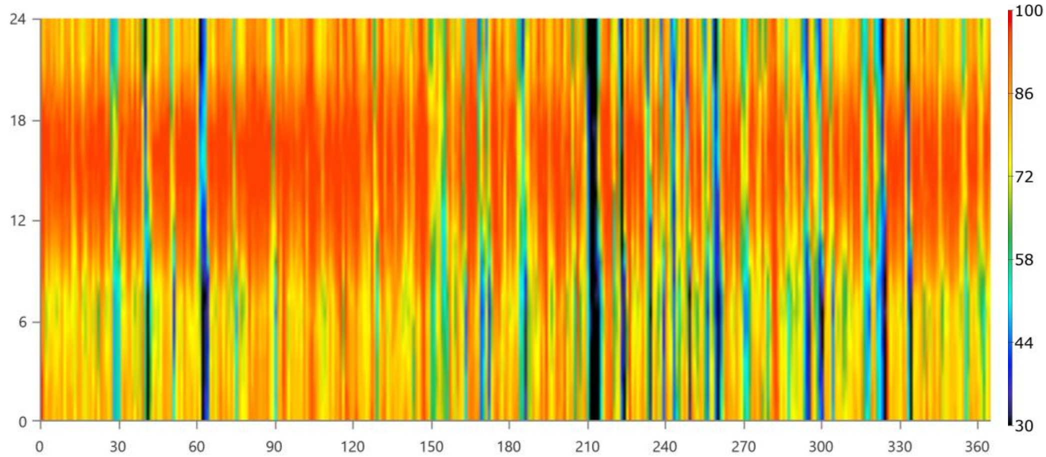



**Figure 4.49:-Hoppecke 12 OPzS 1500 State of Charge (%)forScenario D**

### 4.7.8 Converter: Dynapower SPS – 100for Scenario D

**Table 4.74Dynapower SPS - 100 Electrical SummaryforScenario D**

| Quantity | Value | Units |
|---|---|---|
| Hours of Operation | 6,566 | hrs/yr |
| Energy In | 718,268 | kWh/yr |
| Energy Out | 693,128 | kWh/yr |
| Losses | 25,139 | kWh/yr |

**Table 4.75Dynapower SPS - 100 Statisticsfor Scenario D**

| Quantity | Value | Units |
|---|---|---|
| Capacity | 306 | kW |
| Minimum Output | 0 | kW |
| Mean Output | 79.1 | kW |
| Maximum Output | 306 | kW |
| Capacity Factor | 25.9 | % |

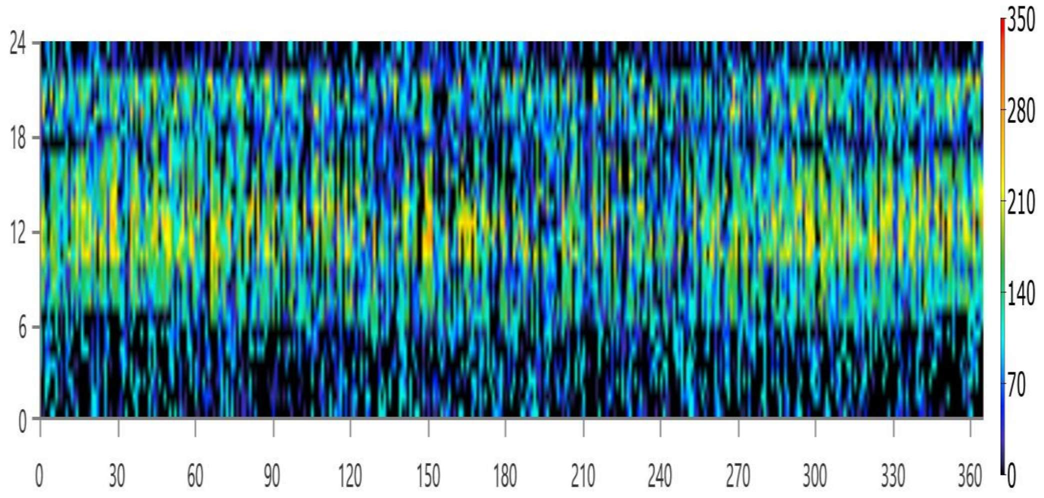



**Figure 4.50:-Dynapower SPS - 100 Inverter Output (kW)for Scenario**

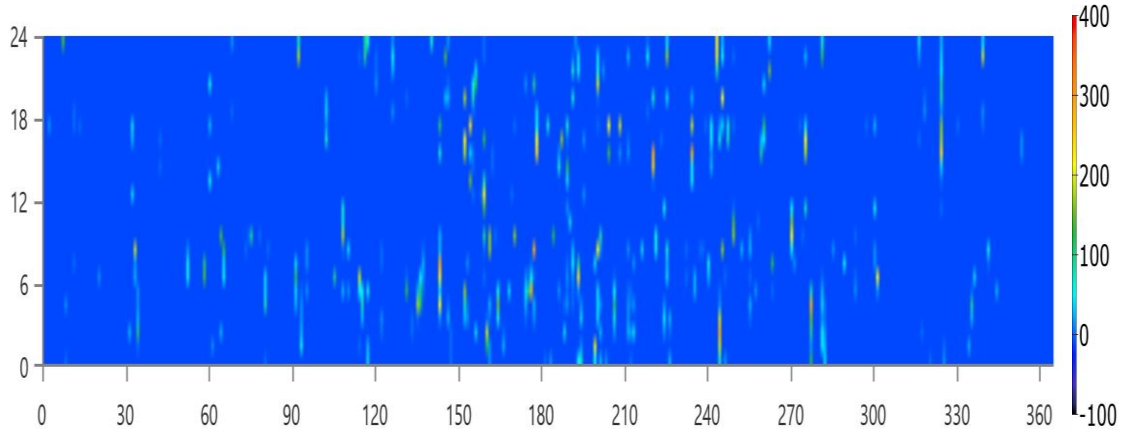



**Figure 4.51:-Dynapower SPS - 100 Rectifier Output (kW)**

### 4.7.9 Fuel Summary

**Table 4.76Biogas Consumption Statisticsfor Scenario D**

| **Quantity** | **Value** | **Units** |
|---|---|---|
| **Total feedstock consumed** | 1,602 | tons |
| **Avg feedstock per hour** | 0.183 | tons/hour |
| **Avg feedstock per day** | 4.39 | tons/day |

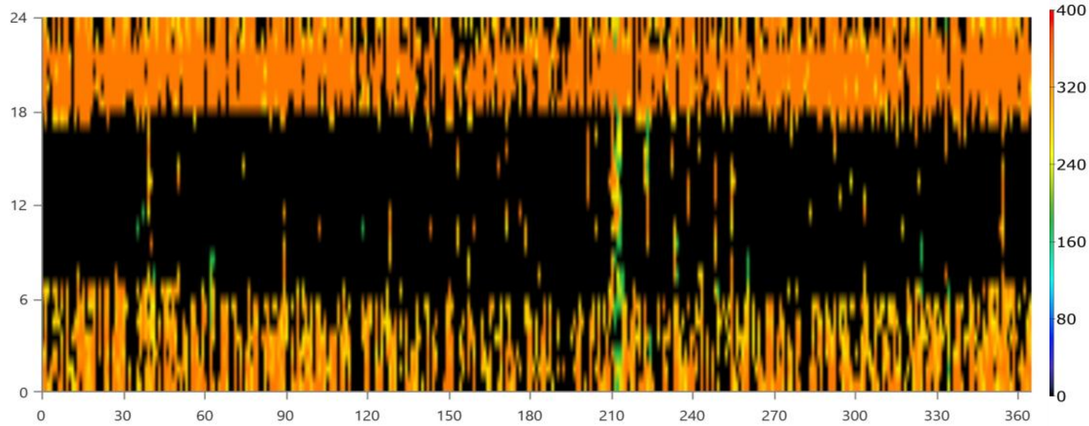



**Figure 4.52:-Biogas Consumption (kg/hr)**

**Table 4.77Emissionsfor Scenario D**

| Pollutant | Quantity | Unit |
|---|---|---|
| **Carbon Dioxide** | 289 | kg/yr |
| **Unburned Hydrocarbons** | 0 | kg/yr |
| **Carbon Monoxide** | 3.20 | kg/yr |
| **Sulfur Dioxide** | 0 | kg/yr |
| **Particulate Matter** | 0 | kg/yr |
| **Nitrogen Oxides** | 2.00 | kg/yr |

**Table 4.78Renewable Summary**

| **Capacity-based metrics** | **Value** | **Unit** |
|---|---|---|
| **Usable renewable capacity divided by total capacity** | 100 | % |
| **Nominal renewable capacity divided by total nominal capacity** | 100 | % |
| **Energy-based metrics** | **Value** | **Unit** |
| **Total renewable production divided by generation** | 100 | % |
| **Total renewable production divided by load** | 126 | % |
| **One minus total nonrenewable production divided by load** | 71.4 | % |
| **Peak values** | **Value** | **Unit** |
| **Renewable output divided by load (HOMER standard)** | 671 | % |
| **One minus nonrenewable output divided by total load** | 100 | % |
| **Renewable output divided by total generation** | 100 | % |

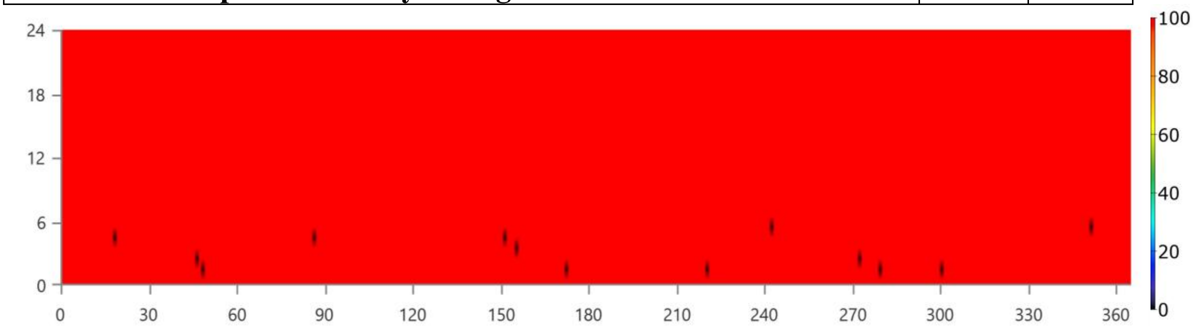



**Figure 4.53:- Instantaneous Renewable Output Percentage of Total Generatio**

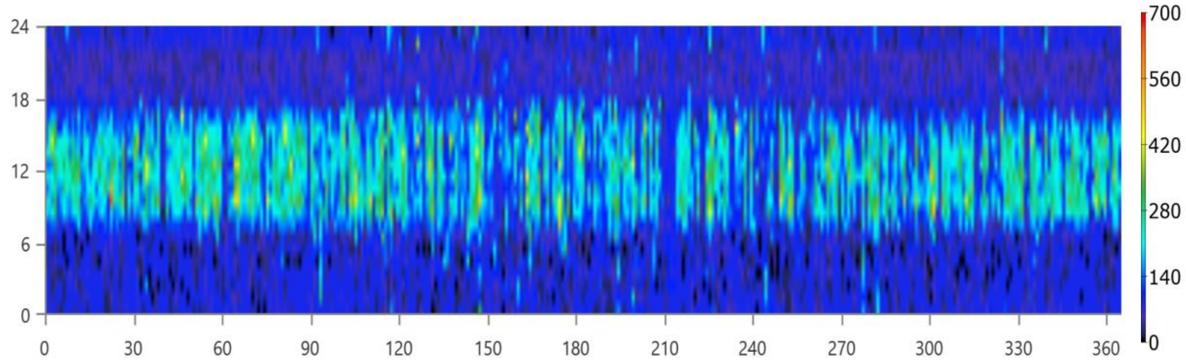



**Figure 4.54:-Instantaneous Renewable Output Percentage of Total Load**

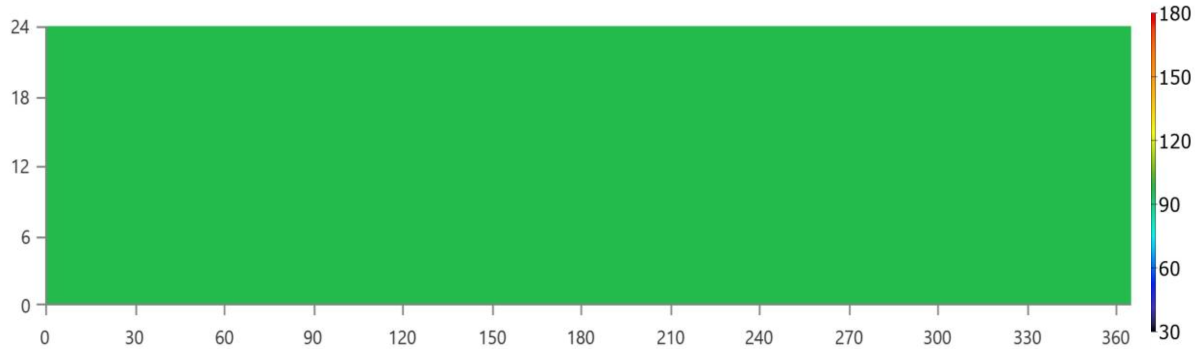



**Figure 4.55:- 100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load**

**4.7.10 Compare Economics**

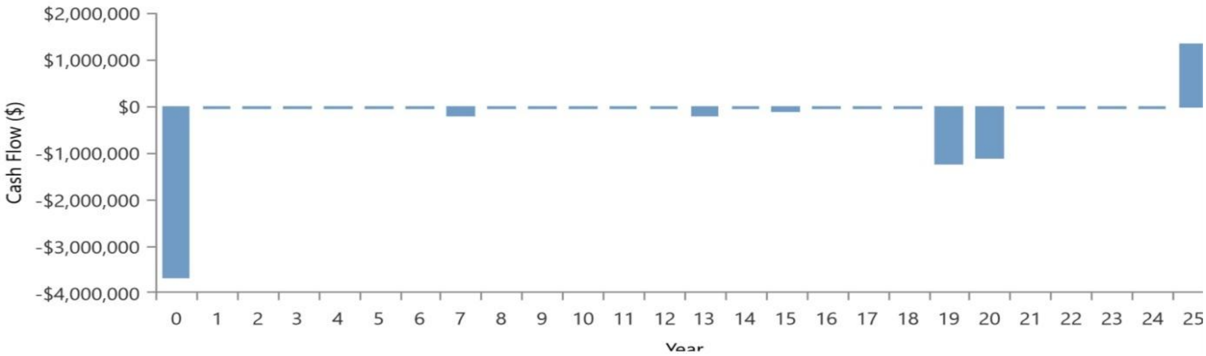
**IRR (%):148**

**Discounted payback (yr):0.759**

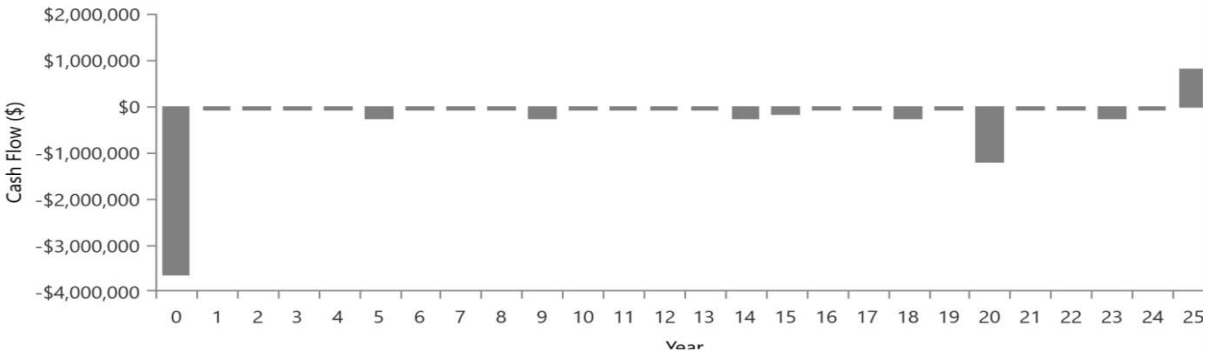
**Table 4.79Simple payback (yr):0.717for Scenario D**

| | Base System | Proposed System |
|---|---|---|
| **Net Present Cost** | $5.63M | $5.20M |
| **OPEX** | $151,342 | $116,216 |
| **CAPEX** | $3.67M | $3.70M |
| **LCOE (per kWh)** | $0.234 | $0.216 |
| **Fuel Consumption (L/yr)** | 2,369 | 1,602 |
| **CO2 Emitted (kg/yr)** | 427 | 289 |

**4.7.11 Proposed Annual Nominal Cash Flowsfor Scenario D**




### 4.7.12 Base System Annual Nominal Cash Flowsfor Scenario D




### 4.7.13 Cumulative Discounted Cash Flowsfor Scenario D

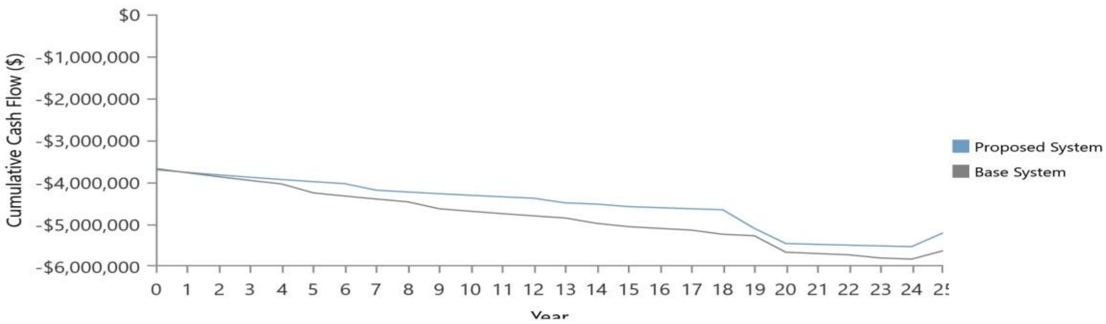


**Figure 5.56:- solar, wind and Biogas Microgrid System**

### 4.7.14 Conclusion

The integration of solar, wind, and biogas energy for off-grid power generation has proven to be technically viable for areas like NijhumDwip, where centralized power grids are absent. With a levelized cost of electricity (LCOE) of $0.216 per kWh, this hybrid system presents a cost-effective solution for meeting off-grid energy demands. This LCOE is impressively low when compared to traditional fossil fuel-based generation methods, such as diesel.

### 4.8 Simulation result compare

#### 4.8.1 Introduction

Adjusting the control settings within the system can play a crucial role in sensitivity analysis, allowing us to investigate how changes to these parameters affect overall performance. This methodology assists system designers in identifying the most cost-effective configurations for specified ranges of control parameters. In this analysis, we've selected two types of sensitivity variables for examination. Sensitivity analysis showcases how output behavior responds to input variations. In HOMER, the user introduces a range of values for a particular input variable during this analysis. A sensitivity variable refers to any variable where multiple values have been inputted by the user. This could include parameters from an hourly dataset, such as load and renewable resource data. Each unique combination of sensitivity variable values results in a separate sensitivity case, which HOMER optimizes independently, presenting the findings in various tables and graphical formats. One of the key applications of sensitivity analysis is addressing uncertainty. It helps assess trade-offs and the additional investments required to generate the intended amount of renewable energy. Moreover, sensitivity analysis can identify which technologies or their combinations perform best under varying conditions. It can also help determine pricing strategies and competitiveness against alternative solutions. In this study, we have examined how fluctuations in solar radiation, wind speed, diesel costs, and biomass availability impact the development of a hybrid renewable energy system. The scenario involving solar PV, wind, biogas, and diesel was chosen for sensitivity analysis due to its impressive cost-effectiveness in terms of COE, NPC, and initial costs. We analyzed six distinct scenarios for the sensitivity results, including variations in wind speed and solar radiation, changes in solar radiation and diesel prices, shifts in biomass resource availability, fluctuations in diesel prices and biomass availability, and variations in both biomass resource and wind speed. The results for these different variables are illustrated in Figures 4.57 .

### 4.8.2 Over all Simulation Result

| Architecture | | | | | | Cost | | |
|---|---|---|---|---|---|---|---|---|
| LR6-60PB (kW) | AWS4.2kW | Bio (kW) | H1500 (#) | Dyn100 (kW) | Dispatch | NPC ($) | LCOE ($/kWh) | Operating cost ($/yr) |
| 831 | 107 | 175 | 1,140 | 306 | LF | $5.20M | $0.216 | $116,216 |
| 2,051 | | 190 | 1,248 | 343 | LF | $5.63M | $0.234 | $151,341 |
| | 346 | 170 | 1,800 | 332 | LF | $8.24M | $0.342 | $126,268 |
| 1,256 | 239 | | 2,886 | 555 | CC | $8.57M | $0.356 | $73,480 |
| 5,069 | | | 4,332 | 740 | CC | $11.3M | $0.470 | $104,429 |
| | 614 | | 5,472 | 3,031 | CC | $16.7M | $0.694 | $146,542 |

| Architecture | | | | | | Cost | | | | System | | Bio | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LR6-60PB (kW) | AWS4.2kW | Bio (kW) | H1500 (#) | Dyn100 (kW) | Dispatch | NPC ($) | LCOE ($/kWh) | Operating cost ($/yr) | CAPEX ($) | Ren Frac (%) | Total Fuel (tons/yr) | Hours | Production (kWh) | Fuel (tons) | O&M Cost ($/yr) |
| 831 | 107 | 175 | 1,140 | 306 | LF | $5.20M | $0.216 | $116,216 | $3.70M | 100 | 1,602 | 3,275 | 532,058 | 1,602 | 57,312 |
| 2,051 | | 190 | 1,248 | 343 | LF | $5.63M | $0.234 | $151,341 | $3.67M | 100 | 2,369 | 4,457 | 786,707 | 2,369 | 84,683 |
| | 346 | 170 | 1,800 | 332 | LF | $8.24M | $0.342 | $126,268 | $6.61M | 100 | 1,396 | 2,899 | 463,839 | 1,396 | 49,283 |
| 1,256 | 239 | | 2,886 | 555 | CC | $8.57M | $0.356 | $73,480 | $7.62M | 100 | 0 | | | | |
| 5,069 | | | 4,332 | 740 | CC | $11.3M | $0.470 | $104,429 | $9.98M | 100 | 0 | | | | |
| | 614 | | 5,472 | 3,031 | CC | $16.7M | $0.694 | $146,542 | $14.8M | 100 | 0 | | | | |

**Figure 4.57:- Over all simulation result**

### 4.8.3 Conclusion

In conclusion, off-grid renewable energy systems offer a sustainable and increasingly viable alternative to traditional energy sources, especially in remote or rural areas. By harnessing renewable resources like solar, wind, hydro, and biomass, these systems can provide reliable, eco-friendly power without the need for connection to a centralized grid. Key benefits include reduced carbon emissions, lower operational costs over time, energy independence, and resilience against grid failures. Technological advancements and decreasing costs of solar panels, wind turbines, and energy storage systems make off-grid systems more accessible and efficient. However, there are challenges to consider, such as the high initial investment, the need for proper system design and maintenance, and the intermittency of some renewable sources. Combining different energy sources (hybrid systems) and investing in energy storage solutions can mitigate these challenges. Ultimately, off-grid renewable energy systems represent a powerful tool in the transition toward a more sustainable, self-sufficient future, aligning with global efforts to reduce environmental impacts and increase energy security.

# CHAPTER 5

# CONCLUSION AND FUTURE WORK

The innovative 100% renewable hybrid energy system that combines solar, wind, and biogas power, along with a charging boat station, presents a sustainable solution to meet the energy and transportation needs of Nijhumdwip, a remote area in Bangladesh. This integrated approach guarantees reliable, affordable, and clean energy while addressing pressing environmental issues, fostering economic growth, and enhancing energy security for the island.

By harnessing solar, wind, and biogas energy, this hybrid system plays a crucial role in lowering greenhouse gas emissions and air pollution, significantly decreasing the reliance on imported fossil fuels. It aligns perfectly with the region's goal of embracing sustainable and low-carbon energy alternatives. The production of biogas from organic waste is vital not only for providing a steady energy source but also for effective waste management, fostering a circular economy where resources are efficiently reused.Moreover, the introduction of a renewable energy-powered charging boat station is a transformative step towards sustainable transportation in Nijhumdwip, where boat connectivity is essential. Utilizing electric boats powered by solar and wind energy, the station minimizes the environmental footprint of traditional fuel-based boats, thus lowering carbon emissions and enhancing air quality around the island. This renewable transportation initiative promotes energy independence by reducing the reliance on costly and hard-to-transport imported fuels.Additionally, the project stimulates local economic development by creating jobs in the renewable energy sector, covering the installation, operation, and maintenance of solar panels, wind turbines, biogas facilities, and the charging infrastructure. A stable and affordable power supply will support local businesses, enhance tourism potential, and provide energy for agriculture and other sectors that depend on electricity for their operations. The biogas plant also serves as an effective solution for local waste management, converting agricultural and organic waste into valuable energy and generating further economic advantages.

While the initial capital investment for the renewable energy infrastructure, including solar panels, wind turbines, biogas plants, and the charging station, may be considerable, the long-term benefits—such as decreased fuel expenses, environmental sustainability, and improved local economies—make this investment worthwhile.

This innovative system plays a vital role in safeguarding the untouched beauty of Nijhumdwip by addressing the environmental challenges linked to traditional energy production, especially in delicate offshore ecosystems. By harnessing local renewable resources, Nijhumdwip can lessen its reliance on outside energy sources and fossil fuels, paving the way for a cleaner, greener, and more resilient future.

The addition of a renewable-powered boat charging station further amplifies these environmental advantages, promoting sustainable transportation options and significantly cutting down the island's carbon emissions. This hybrid approach serves as a shining example for other rural and remote coastal communities, showcasing how a diverse array of renewable energy can power daily activities and sustainable travel while building resilience against climate change and energy uncertainty. With thoughtful implementation, strategic investments, and active community participation, Nijhumdwip is well-positioned to champion a future that is both renewable and self-sustaining.

## 5.1 Future Work

Any engineering study can't investigate all important points at once. In subsequent works, it will be necessary to examine and reexamine certain points independently of the research that was used for this thesis; that is by all accounts of the greatest significance. The research creates opportunities for work in numerous other related fields. For further investigation, the following hybrid energy options have been identified:

### 5.1.1. In-Depth Feasibility and Tailored Site Analysis

**Thorough Resource Mapping:** It's essential to undertake a detailed, long-term assessment of resources on Nijhumdwip, taking into account the variations in wind, solar radiation, tidal influences, and biomass through different seasons. Gathering data over an extended time frame will offer more accurate forecasts for energy generation capabilities.

**Microgrid Connectivity**: Consider the potential for connecting the hybrid renewable energy system with other local or national grids. This interconnection can enhance energy security and lower costs. Implementing a microgrid model would also bolster resilience against natural disasters.

### 5.1.2. Innovations in Hybrid EnergyTechnologies

**Next-Generation Energy Storage:** Explore and test cutting-edge energy storage options, such as solid-state or flow batteries, and hydrogen storage solutions. These technologies could significantly improve the reliability and economic efficiency of the system.

**Smart Grid and Energy Optimization Systems**: Developing an advanced energy management system that leverages real-time data—like weather updates, energy demand, and supply—can optimize the hybrid system's performance. Utilizing AI and machine learning can help in dynamically predicting and adjusting energy production to minimize inefficiencies and maximize output.

**5.1.3. Creating Sustainable Hybrid Fishing Boat Solutions**

**Electric or Hybrid Fishing Vessel Development:** Future efforts should aim at designing and piloting fishing boats powered by electric or hybrid technology, capable of recharging using renewable energy at designated stations. Research should focus on enhancing these boats' operational efficiency through battery management and energy recovery during slowing maneuvers, leading to lower operational costs and reduced environmental footprints.

**Energy Docking Station Expansion:** Develop the idea of energy docking stations further by incorporating fast-charging infrastructure powered by the hybrid energy system. This will facilitate quick recharging of fishing vessels, minimizing downtime and ensuring maximum operational efficiency.

**5.1.4. Impact on Local Economy and Community Welfare**

**Economic Models for Sustainability**: Future research should delve into economic frameworks that balance the initial investment of renewable energy infrastructure with the long-term savings on fuel and upkeep. It's crucial to assess the job opportunities created within the renewable energy sector, alongside the wider socio-economic advantages for the local community.

**Socio-Economic Impact of Energy Transition**: Further investigations could highlight the social benefits stemming from the adoption of renewable energy solutions. This includes enhanced electricity accessibility, improved working conditions for fishing communities, and shifts in social dynamics fostered by cleaner, more sustainable technologies.

**5.1.5. Environmental Impact Assessments**

Long-Term Environmental Monitoring: It's important to conduct studies on the environmental repercussions of implementing a hybrid renewable energy system, focusing on its effects on local ecosystems, such as marine life and coastal biodiversity. Particular care should be taken to evaluate the potential impact of wind turbines, solar panel installations, and tidal energy devices on marine habitats.

**Carbon Emissions Reduction Analysis:** A thorough carbon footprint assessment is necessary to quantify the reductions in greenhouse gas emissions resulting from the transition from diesel generators to hybrid renewable energy systems. Additionally, exploring prospects for carbon credits or offset programs would be beneficial.

### 5.1.6. Scalability and Replicability

**Replicability to Other Coastal Communities**: An investigation into how the insights from the Nijhumdwip project can be scaled or adapted for other fishing communities within Bangladesh and in coastal regions worldwide is essential. Identifying the key factors that contribute to the success (or challenges) of the system will facilitate broader implementation.

**Modular Energy Solutions:** Researching modular renewable energy systems that can be easily replicated or scaled according to the community's energy needs will support the future expansion of the project.

**Policy and Regulatory Framework**

**Government Support and Policy Development:** To promote renewable energy adoption, future efforts should involve close collaboration with government bodies. This includes crafting policies that provide incentives specifically for the fishing sector, establishing regulatory frameworks for offshore energy production, and creating financial models that attract private investment.

**Collaboration with NGOs and Research Institutions:** It's essential to encourage partnerships among academia, government entities, and NGOs to foster innovative renewable energy solutions. Such collaboration will also play a crucial role in ensuring the sustainability of energy projects, especially in remote areas.

**Community Engagement and Awareness**

**Capacity Building Initiatives:** Future research should emphasize the creation of training programs aimed at empowering local communities. This will facilitate not just the effective operation and maintenance of renewable energy systems but also bolster community ownership of the energy transition.

**Integration of Local Knowledge:** It's important to weave local insights into the design of energy systems to ensure that our solutions truly resonate with the cultural and practical needs of the fishing community. By adopting community-driven strategies, we can enhance both adoption rates and the long-term viability of these systems.

**Future Collaboration with Global Experts**

**International Partnerships for Innovative Technology:** We should actively seek opportunities for global cooperation with experts in renewable energy, particularly focusing on offshore wind, wave energy, and energy storage solutions. Leveraging knowledge from worldwide leaders can significantly expedite the shift towards advanced energy technologies.

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