Feasibility Study of Renewable Energy Integration in an Islanded Microgrid: A Bangladesh's Perspective

By

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Declaration

It is hereby declared that

1. The project submitted is my own original work while completing degree at Brac University.
2. The project does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The project does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

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Approval

The project titled “Feasibility Study of Renewable Energy Integration in an Islanded Microgrid: A Bangladesh's Perspective” submitted by

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of Fall, 2024 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Electrical and Electronic Engineering on [12/12/24].

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Abstract/ Executive Summary

This study proposes a design of a microgrid took into account the Bangladeshi island of Dublar Char. A scenario-based analysis which comprises one system of standalone PV and wind systems along with battery storage and another system considering backup generator have been considered based on the calculated load requirement of the Dublar Char. The average load demand of the Dublar Char, Island area is 5,246.9 kWh/day. Life Cycle Cost analysis claims, 20% load dependency for PV and battery storage and 80% load dependency for wind became the optimum design solution for the Dublar Char community. The total land required for PV module, Wind Turbine and Battery storage system, would be approximately 2 acres. Based on a 20-year project life, the return on investment is expected to be 9.09 years If the diesel generator is capable of providing a backup energy supply to the PV night load demand, the LCC will be significantly lower than regular and less space will need to be occupied (1.5 acres of land). Based on a 20-year project life, the return on investment is expected to be 6.27 years.

Keywords: Dublar Char, microgrid, photovoltaic, wind, payback.

Dedication

This work is dedicated to my parents for their endless love, support and encouragement.

Acknowledgement

I would like to express my deepest gratitude to my supervisor, Prof. Dr. Md. Mosaddequr Rahman, for his invaluable guidance, support, and encouragement throughout the course of this research. His insights and expertise were instrumental in shaping this thesis. Special thanks to the members of energy research group for their constant support and for making this journey enjoyable.

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Chapter 1: Introduction

1.1 Background

The global advancement of DC microgrid technology is rapidly converging, offering innovative solutions for modern energy challenges. A microgrid is an interconnected system of loads and dispersed energy resources that functions as a single controlled entity. It can operate in both grid-connected and islanded modes, making it a promising approach for bringing electricity to rural and remote areas [1]. Several countries around the world, such as Australia, Bangladesh, India, and South Africa, are doing in-depth research to make energy-efficient and reliable microgrid-based electricity delivery systems for rural areas [2-3]. Advanced microgrids allow local resources to work together to save more money, make energy last longer, and make money through market participation [4]. Currently, Bangladesh heavily depends on natural gas, accounting for approximately 72% of commercial energy consumption and 63.19% of electricity generation [5,6]. Government measures have led to the generation of approximately 1,835 MW of electricity from renewable energy sources in Bangladesh, including hydropower [15]. Bangladesh is projected to require 34,000 MW of power by 2030 to sustain a 7% increase in its economic growth [7]. However, the supply of natural gas is insufficient to meet the country's growing electricity demand [8]. Also, importing energy in the form of fossil fuel can be costly in both economic and environmental terms, hence exploring other distributed energy systems in islands can be more sustainable and this is most evident in the form of microgrids, which are flexible, controllable, and capable of disconnecting from the regular electric grid and operating independently [9]. With its 574 km shoreline and remote islands in the Bay of Bengal, Bangladesh has favorable conditions for utilizing its abundant solar irradiance and wind resources [8]. Renewable energy sources such as solar photovoltaic (PV) and wind energy are increasingly being adopted to address this gap as, solar PV can generate enough electricity with an annual sun irradiation of around 1700 kWh/m2 and annual average wind speeds in coastal regions exceed 6.5 m/s at a height of 20 m in Bangladesh [9-10]. Wind energy can provide mechanical or electrical power without emitting pollutants [11]. Similarly, solar PV technology has seen significant growth in rural Bangladesh, primarily through solar home systems (SHS), which meet basic energy needs in a cost-effective way. Several hybrid off-grid mini-grids using PV systems are operational in the country [3,12,13]. In addition, a commercial analysis of a mini-grid-based electricity generating system for Bangladesh has been conducted [13]. Recent research on similar systems in Bangladesh, such as a sustainable microgrid for Kutubdia Island, highlights the feasibility of such designs in terms of return on investment, CO2 emissions, renewable fraction, and other metrics [14]. Existing studies have evaluated renewable energy-based microgrid systems, including combinations of PV, wind, and micro-hydro power systems [15]. A notable study introduced a hybrid system integrating PV arrays, wind turbines, and battery storage through a common DC bus [18]. In 2013-15, researchers developed a solar, wind, and generator-based hybrid power generation system for Sandip Island, generating 25.5 kW of power and a hybrid system for Nijhum Dwip [21]. In 2019, a study revealed a hybrid system using solar, wind, and biomass generators, but this power is insufficient for the Rohingya camp on Boalkhali island [7, 19]. Islanded microgrid systems have recently gained popularity in rural areas of Bangladesh due to their ability to provide a considerable amount of reliable energy to the community. This study was discussed in [3], which suggested that their hybrid mini-grid technology is technically and economically viable for Bangladesh. In 2020, a study revealed that the current diesel-based system is not viable for the island's people due to high electricity costs and net present costs. A PV/Wind/Diesel/Battery hybrid microgrid is more feasible, costing around 28% less and reducing carbon dioxide [20]. In 2023, another study explored the design of a 100% renewable energy-based off-grid system for St. Martin's Island, Bangladesh, utilizing MILP optimization in MATLAB® to efficiently meet energy demand [17]. However not much study found focusing the island area of Bangladesh. This work considers an islanded area to assess the feasibility of hybrid renewable energy source considering microgrid system.

1.2 Objective

This study proposes a feasibility assessment of a renewable energy integrated microgrid system comprising of photovoltaic (PV), wind energy, and a battery storage system in Dublar Char, a cluster of offshore islands or sandbanks located off the southern coast of the Sundarbans in Bangladesh [16]. Sizing and cost optimization ensure the most efficient use of the PV, Wind, and Battery Storage hybrid system, resulting in optimal configurations that meet both investment and demand load requirements [17]. The primary objectives of this study are as follows:

- Propose a hybrid microgrid systems that integrates PV, wind energy, and battery storage system.
- Return on Investment study of the proposed systems.

1.3 Scope of the Work

This study emphasizes system engineering aspects to ensure the proposed microgrid's feasibilty:

- Irradiation and Energy Calculation of the proposed area
- Sizing of PV panels, wind turbines and battery
- Lifecycle cost (LCC) analysis of the systems
- Analyzing the energy payback period

This research builds upon existing studies on renewable energy microgrids in Bangladesh, including hybrid systems that integrate PV and wind energy. The study also references methodologies like the Sustainable Microgrid Analysis framework used for similar systems in Bangladesh [14].

1.4 Organization of the Work

Chapter 1 introduces the study's background, objectives, scope, and structure, highlighting renewable energy microgrids and their relevance to Dublar Char. Chapter 2 delves into the theoretical background, including solar radiation, wind energy potential, and environmental impacts on hybrid microgrids. Chapter 3 outlines the research methodology, emphasizing system design, energy demand estimation, and analysis techniques. Chapter 4 presents the results, focusing on energy output, cost efficiency, and environmental effects. Chapter 5 concludes with key findings and recommendations for implementing the proposed microgrid system

Chapter 2: Theoretical Background

2.1 Photovoltaic Energy

Photovoltaic energy is generated by transforming solar incident energy into electrical energy using a photoelectric effect-based technology. A renewable, eternal, and non-polluting source of energy, which can be generated in a variety of ways, from smaller units for subjective use to large photovoltaic facilities. The PV cell is the fundamental component of a PV system. Individual cells can range in dimension from approximately 0.5 to 4 inches. However, a single cell only produces 1 or 2 Watts, which is not capable to power up the small devices. PV cells are connected to each other electrically in a package called a PV module or panel that is weatherproof. PV modules come in different sizes and can make different amounts of electricity. The amount of electricity a PV module can make depends on how many cells it has and how big its surface area is.

2.2.1.Definition

Extraterrestrial radiation: Solar radiation incident outside the earth's atmosphere is called extraterrestrial radiation.

Solar constant (G_{sc}): solar constant is the energy from the sun per unit time received on a unit area of surface perpendicular to the direction of propagation of the radiation at mean earth-sun distance outside the atmosphere.

Beam Radiation (I_B): The solar radiation received from the sun without having been scattered by the atmosphere [22].

Air mass (M): The ratio of the mass of atmosphere through which beam radiation passes to the mass it would pass through if the sun were at the zenith.

Diffuse Radiation (I_{DC}): The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere.

Irradiance (W/m^2): The rate at which radiant energy is incident on a surface per unit area of surface.

Latitude (L): The angular location north or south of the equator, north positive.

Slope/Tilt angle (β): The angle between the plane of the surface in question and the horizontal.

Surface azimuth angle (γ): the deviation of the projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, and west positive.

Angle of incidence (θ): The angle between the beam radiation on a surface and the normal to that surface. Zenith angle (θ_Z) and the azimuth angle (γ) is necessary to calculate the total angle of incidence.

Zenith angle (θ_z): The angle between the vertical and the line to the sun, that is, the angle. of incidence of beam radiation on a horizontal surface.

Solar altitude angle (α_s): The angle between the horizontal and the line to the sun that is, the complement of the zenith angle.

Solar azimuth angle (γ_s): The angular displacement from south of the projection of beam.

Declination angle (δ): The angular position of the sun at solar noon. The angular position of the sun at solar noon , δ can be calculated by the derived equation given below,

$$\delta = 23.45° \sin\left[\frac{n + 284}{365} * 360°\right] \quad (2.1)$$

Where,

N = Number of days after 21 March

This particular declination angle is calculated on the nth day of the year.

Hour angle (H): The angular displacement of the sun east or west of the local meridian due to rotation of the earth on its axis at 15° per hour; morning negative, afternoon positive [22].

From the perspective of northern hemisphere, hour angle is negative from the sunrise time S_r, H_s is the sunrise angle and t are the time of a day in 24-hour format clock.

$$H = -H_s + 2\frac{H_s}{T}(t - S_r) \quad (2.2)$$

$$H_s = cos^{-1}(-tan\delta . tan\gamma) \quad (2.3)$$

Altitude angle (α_S)**:** Altitude angle is the angle between the sun and the local horizon directly beneath the sun. The formula of solar altitude angle(α_S) combines with latitude(L), declination angle(δ) and hour angle (H)[9]. The equation is known as,

$$\text{Cos}\,(\theta_z) = Sin(\alpha_S) = Cos(L)Cos(\delta)Cos(H) + Sin(L)Sin(\delta) \qquad (2.4)$$

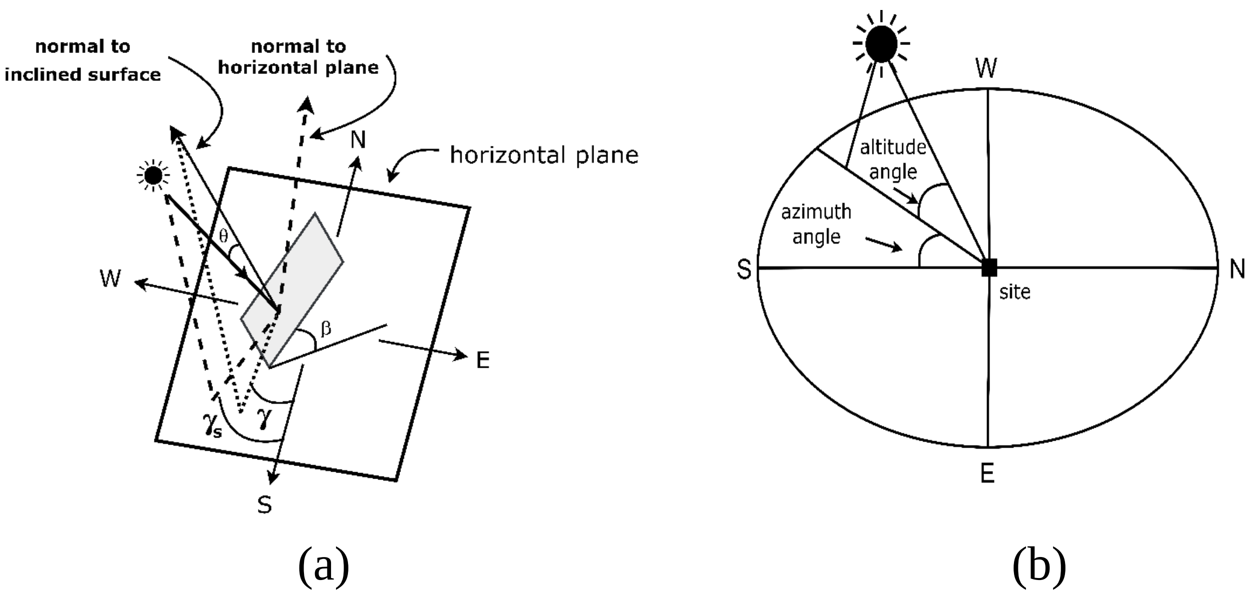

Figure 2.1: Illustrating the collector azimuth angle γ_s Incident angle θ and tilt angle β (a) along with the solar azimuth angle γ and altitude angle α_S (b).

2.2.2 Irradiation Model

Initially, a study was initiated to simulate a system compatible enough to collect all the irradiation on a collector panel. The sun's irradiation is divided into three types direct irradiation, diffuse irradiation and reflection. Estimating the diffusion energy that is diffused by the atmosphere is harder due to the impact of weather conditions and geographic location on the diffusion rate. The final component of the isotropic model is the ground reflected irradiation generated by the subsurface and any other nearby objects.

Liu and Jordan came up with an isotropic model. Later, THRELKELD and JORDAN developed a modified model that was utilized in the ASHRAE solar day clear flux model.[23]

2.2.3. ASHRAE Modifications

This specific modified model was developed by Threlkeld and Jordan (1958) titled as American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Clear Day Solar Flux Model, suitable for the dusty atmosphere. This isotropic diffuse model has introduced and declared the value of 3 factors named as apparent extraterrestrial flux (A) generated due to irradiance of sun, dimensionless factor (K) also knows as the optical depth and the sky diffuse factor (C) [23].

The electricity power generated by PV systems is directly related to the solar energy received by the PV module, while the PV module can be placed at any orientations and any tilt angles, but most local observatories only provide solar irradiance data on a horizontal surface. Thus, an estimation of the Solar radiation striking a Collector (I_C), is calculated by adding the direct or beam radiation (I_{BC}), Diffuse radiation (I_{DC}), and reflected irradiance (I_{RC}).

$$I_C = I_{BC} + I_{DC} + I_{RC} \tag{2.5}$$

collector solar radiation (I_C), beam radiance, reflected radiance and diffuse radiance are expressed by W/m^2 [2].

2.2.4. Solar Irradiation Calculations

2.2.4.1 Beam Irradiation

Beam solar irradiance can be expressed as the amount of energy that has to travel through the atmosphere which is easy to be calculated though the other factor of the atmosphere as dust, cloud, pollution level and the humidity of the weather varies from place to place. To calculate the value of beam solar irradiance, the following equations are well established,

$$I_B = Ae^{-kM} \tag{2.6}$$

Equations stated above, I_B is the normal rays reaching to the earth surface, (A) is the apparent extraterrestrial flux lost in space.

$$A = 1160 + 75\sin[\frac{360}{365}(n - 275)] \quad (2.7)$$

Optical depth termed as the dimensionless factor (K)

$$K = 0.174 + 0.035\sin[\frac{360}{365}(n - 100)] \quad (2.8)$$

and the air mass ratio (M)

$$M = \frac{1}{sin\alpha_s} \quad (2.9)$$

Total solar beam irradiance I_{BC}, can be calculated from the value of normal ray irradiation I_B.

$$I_{BC} = I_B cos\theta \quad (2.10)$$

Now, the solar azimuth angle (γ) is illustrated as the product of the declination angle (δ) and the hour angle divided by the surface tilt (β)

$$sin\gamma = \frac{cos\delta cosH}{cos\alpha_s} \quad (2.11)$$

Moreover, altitude angle, surface azimuth, solar azimuth and the angle of the surface tilt associated within this system is calculated to determine the incident angle (θ) of the sun [24]

To be precise, incident angle is the normal ray angle on the photovoltaic panel face and the solar beam irradiance (I_{BC}).

$$cos\theta = cos\alpha_s \cos(\gamma - \gamma_s)\, sin\beta + \sin\alpha_s \cos\beta \tag{2.12}$$

2.2.4.2 Diffuse Irradiation

The diffuse irradiation is to be calculated as the sky is considered as isotropic and the amount of cloud, dust or brighter day with a clear sky and factors like a cloudy day with rain is expressed as the factor C while calculating the diffuse irradiation of any side of the collector [24].

$$I_{DF} = CI_B \frac{1 + cos\beta}{2} \tag{2.13}$$

$$C = 0.095 + 0.04\sin[\frac{360}{365}(n - 100)] \tag{2.14}$$

2.2.4.3 Reflected solar irradiance

I_{RC}, is the available solar irradiation on the collector panel after the reflection from any albedo (ρ) surface expressed as reflectance.

$$IR_C = \rho I_B (sin\beta + C)\, (\frac{1 - cos\beta}{2}) \tag{2.15}$$

2.2.4.4 Environmental Impact

The presence of clouds has a negative impact on the efficiency of solar energy conversion. Because of the existence of clouds, a substantial part of the sun's rays may be unable to reach the earth's surface. The amount of radiation energy emitted by the sun and gathered on a surface may be quantified as solar insolation, which can be adjusted to account for cloud density, height angle of the sun's position, and other factors depending on a particular time period [25].

Mathematical equations related to cloud impacts are;

$$E_{sunny} = \int_{T_{SR}}^{T^{SS}} (Isin\alpha + 0.1I)\, dx \tag{2.16}$$

$$E_{Cloudy} = \int_{T_{SR}}^{T^{SS}} 0.2I\, dy \tag{2.17}$$

Where,

T_{SS} = Time of sunset

T_{SR} = Time of sunrise

Proposed solar panels total energy given as,

$$E_{pv\_tot} = x * E_{sunny} + y * E_{Cloudy} \tag{2.18}$$

Where,

x = Number of sunny days

y = Number of cloudy days

2.3 Wind Energy

The generated power to a wind turbine is dependent on the air density, ρ (usually about 1.2 kg/m^3), the swept area, A_{wind} of the turbine blades, and the wind speed, V. Wind speed is clearly the most dynamic of these parameters [23].

The following equation describes the energy, E_{wind} that can be extracted from the wind turbine [23]:

$$E_{wind} = \frac{1}{2} A_{wind}\, \rho\; C_p \int V^3\, dt \tag{2.19}$$

Here, the maximum theoretical efficiency of a rotor is 59.3% [23], is called the Betz efficiency, C_p.

2.4 Total Electrical Energy Calculations

The total required solar incident energy (E) for the proposed system can be calculated using the following equation [26]:

$$E = A_p \int_{TR}^{TS} I \, dt \tag{2.20}$$

Where A_p is the area of the panel, TR and TS are the sunrise and sunset times respectively, and E is the incident solar energy.

The required demand load (L_{load}) needs to be set in order to figure out what size solar panel is needed to cover the allocated load demand.

Later, corrected load ($L_{load\_corrected}$) has been calculated to evaluates the Battery utilization efficiency, η_B and Wiring efficiency, η_W [27].

$$L_{load\_corrected} = L_{load} * \eta_W * \eta_B \tag{2.21}$$

Considering PV array degradation factor (PV_{de}), the output electrical energy, E_{pv} of a PV module can be estimated.

$$E_{pv} = Batt_{capacity} * PV_{de} * \frac{E_{pv\_tot}}{1000} * Line\_Voltage \tag{2.22}$$

Required, Number of PV modules can be estimated considering 48V $Line\_Voltage$ from the power line supply from the PV sources.

$$Number\ of\ PV = \frac{E_{pv}}{Nominal\ Power\ of\ a\ PV\ module} \tag{2.23}$$

Furthermore, required battery capacity ($Batt_{cap}$) for this system can be estimated utilizing the battery temperature correction factor ($Batt_{temp}$) and the depth of discharge ($Batt_{soc}$) of the battery [27].

$$Batt_{capacity} = \frac{L_{load\_corrected}}{Batt_{voltage}} * Batt_{temp} * Batt_{soc} \tag{2.24}$$

In this study, the total energy from the proposed system is comprised of photovoltaic energy, E_{pv} and wind energy, E_{wind}.

Total energy, E_{total} from the system can calculated from equation (1),

$$E_{total} = E_{pv} + E_{wind} \tag{2.25}$$

Required, Number of Wind Turbines can be estimated considering Horizontal-axis wind turbines,

$$Number\ of\ \text{Wind Turbine} = \frac{Allocated\ Load\ Demand\ for\ Wind\ Energy}{E_{wind}} \tag{2.26}$$

2.4.1 Inter-row distance of PV array

Determining the optimum distance between each row when designing a tilted or ground-mounted PV system array can be difficult. To avoid unintentional shading from modules ahead of each row, equation (4) needs to be utilized [31].

$$D_{pv} = D_{min} + W_{pv}\ Cos(\theta) \tag{2.27}$$

Here, D_{pv} denotes the inter-row distance of PV array, D_{min} represents the minimum row spacing of the PV module, W_{pv} is the width of a PV module and θ is the surface tilt angle.

2.5 Life Cycle Cost Analysis and Payback

This study intends to examine the cost benefit analysis of the proposed system for the selected location to meet part of the growing demand for electricity. Cost benefit analysis provides the methodological framework which allows for an overall evaluation of projects by taking into account the economic profit (benefit) of producing electricity using PV solar system and wind turbine [30]. Each unit of electricity produced using PV solar system and wind turbine will replace a unit of electricity produced from local grid.

The costs of a PV and wind system include of procurement and control system operation expenses. A system's decommissioning cost or salvage value can be determined at the end of the system's lifespan. The method of life cycle costing, takes into account the time value of money and all costs connected with a system over its lifetime.

Two phenomena affect the value of money over time. The inflation rate, i, is a measure of the decline in value of money. The discount rate, d, relates to the amount of interest that can be earned on principal that is saved. If money is invested in an account that has a positive interest rate, the principal will increase from year to year [27].

The present worth factor, PR is a factor which is used to indicate the present value of cash to be received in the future and is based on the time value of money [27]. This factor is a number which is always less than one, i.e., the number of periods over which payments are to be made.

$$PR = (\frac{1+i}{1+d})^n \tag{2.24}$$

For the item to be purchased *n*th number of years later, the present worth value, PW is given by,

$$PW = C_o(PR) \tag{2.25}$$

Here, C_o is the initial cost of the particular equipment.

In order to estimate the economic value of energy, electricity tariff, E_T and annual electricity generation, E_G need to be utilized [30].

$$C_{in} = E_T \; x \; E_G \tag{2.26}$$

Where, C_{in} is gained money from source energy.

Furthermore, annual electricity generation, E_G need to be evaluated for generated energy source in each year.

$$E_G = E_{g1} \; x \; (1 - P_{DR})^n \tag{2.27}$$

Here, E_{g1} is the initial generated energy by the PV module or Wind Turbine system and P_{DR} stands for the degradation rate of the PV module or Wind Turbine system.

Energy payback time (EPBT) [29] refers to the amount of time required for a system to obtain an electrical balance. To determine the economic benefits of a micro grid system, the net present values (NPV) which is the life cycle cost and energy payback time of this system throughout the lifetime of this forecasted area have been determined [29].

The NPV a of an investment is given by equation (2.28) [30],

$$NPV = \sum_{n=1}^{y} (C_{in} - C_{Out})(1 + C_{DR})^{-n} \tag{2.28}$$

Where, C_{in}, C_{Out}, C_{DR}, y, and n have been set up with cash inflows and cash outflows, discount rate, project lifespan, and the number of the year, respectively. The revenue earned by the proposed system, such as revenue from power production, is denoted by C_{in} . C_{Out}, refers to the total amount of money spent on the system, including the initial investment, inverter replacement, and battery replacement.

Chapter 3 Design Methodology

This study considers an island Dublar Char to analyze the feasibility of the renewable energy based microgrid system. PV and wind-based microgrid system took into account. The location of Dublar Char, which is in the Khulna division of Bangladesh and is surrounded by the Sundarbans. This site is located at 21.74° N latitude [32] and has an area of around 80 square kilometers [33].

In this study, solar and wind energy have been calcuated theoretically, considering that the surface tilt angle is the same as the latitude angle at that particular location and that the air speed at 30 m height is 5-6 m/s [34] throughout the entire year. The daily peak power consumption of Dublar Char has been determined considering the references [35-37] to be 268.6 kw for 400 households, 150 mini-local markets with fans, lights, and refrigerators, and a large commercial cold storage. The anticipated daily electrical load energy usage for this island is calculated 5,246.9 kWh [38].

In order to calculate the number of PV and wind energy sources coupled with battery energy storage, seven scenarios have been considered based on the daily energy demand. The PV system is responsible for fulfilling the energy demand in seven scenarios at 10%, 20%, 40%, 50%, 60%, 80% and 90% of daily demand, while the wind energy system is accountable for 90%, 80%, 60%, 50%, 40%, 20% and 10% of daily demand in scenarios 1 through 7, respectively. In this study, 90%-100% of the load dependency on PV or wind energy is purposefully overlooked due to a lack of reliable wind data, limited land capacity, extreme weather calamity in the islanded area, and a lack of clear policy and government initiatives [39-41].

Figure 3.1 shows the block diagram of the first system comprising with PV and wind energy along with the battery storage. This system is considered to assess the optimal number of panels, turbines and battery requirements. Furthermore, additional feasibility analyses taking non-renewable energy sources into account have been conducted which is shown in figure 3.2. Figure 3.2 shows the block diagram of the second studied system where diesel generator is considered as backup

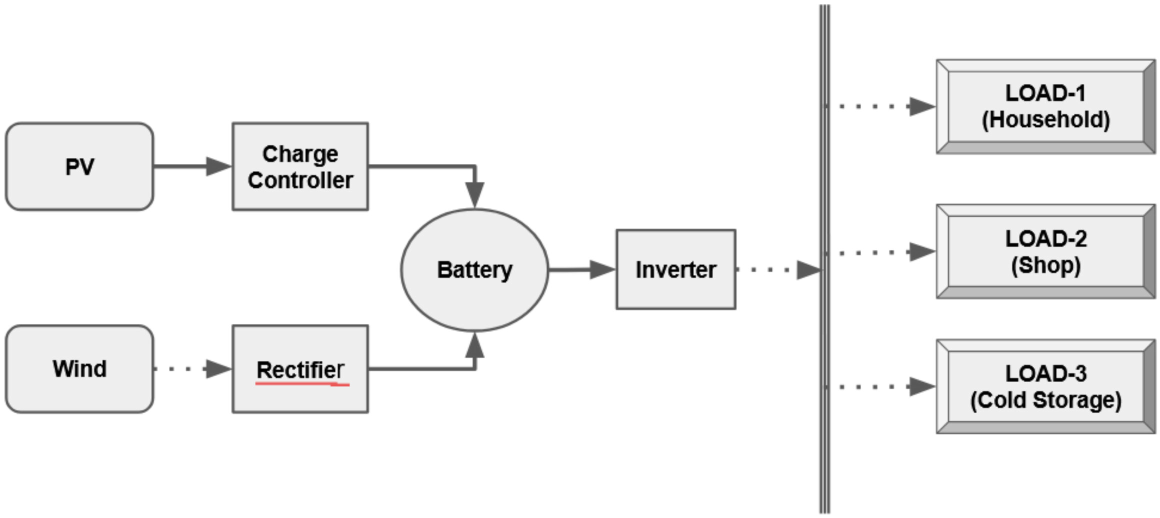

Figure 3.1: Block diagram of the studied case only for renewable energy sources.

source for the night loads. Therefore, it has been proposed that the community install a diesel-powered electric generator to provide backup power at night. At this point, the load demand has been shared with non-renewable energy in the PV section. The load-demand sharing ratio will be based on the less electrically generated output by the PV system.

For the purpose of designing a PV system, a 1.6-square-meter, 250W panel with a maximum voltage of 30.6V has been chosen. The PV array degradation factor, wire efficiency, and battery utilization efficiency have all been taken into account to estimate the number of PV system array modules [42]. Besides, the number of batteries required for each scenario has been determined, taking into account the 60% demand load of the designated PV system, so that sufficient energy demand can be supplied at night. To develop this system, a 12V, 150Ah (lead-acid) battery has been utilized with a 90% temperature correction factor and 80% depth of discharge [42]. Furthermore, a 50 KW horizontal axis downwind based wind turbine with a swept area of 290 square meters has been chosen for the purpose of wind energy system design [43]. This smaller wind turbine has a hub height of 25 meters and can accommodate wind speeds of around 4.5 m/s at that location [44].

This study assessed 20 years of life cycle cost to determine the ideal scenario-based design for this island. The payback analysis has been estimated using an optimal scenario-based approach, where the discount rate of the system has been considered is 7% [44] and the annual energy degradation rate for PV is 0.50% and wind is 1.6% [45].

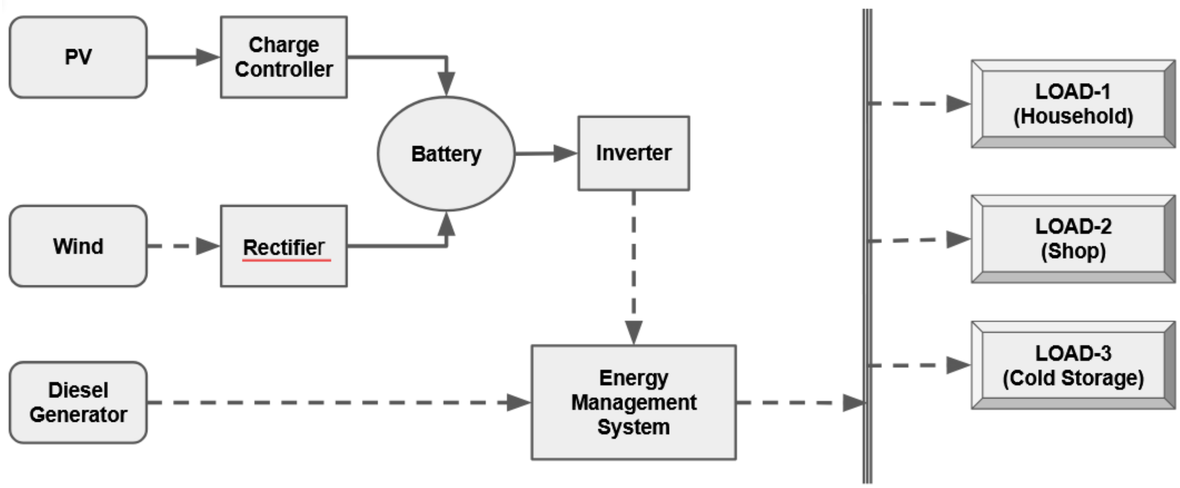

Figure 3.2: Block diagram of the studied case considering backup diesel generator with renewable energy sources.

3.1 Load and Energy Calculation

Table 1: Demand and energy consumption for 400 households

Appliance	Power rating (W)	Quantity	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
Actual Load Demand					
LED Light Bulbs	20	3	60	6	360
Phone charging	15	2	30	8	240
Rechargeable Table Fan	30	1	30	12	360
Prospective/future Load Demand					
LED TV	40	1	40	8	320
Ceiling Fan	75	2	150	18	2700
Fridge	107	1	107	24	2568
TOTAL			**417**		**6548**

Different households had different load and energy consumption demands, hence, the total load Demand and energy consumption for 400 households

- Total load demand for 400 households = 1,66,800 W
- Total energy consumption for 400 houses = 26,19,200 Wh = 2619.2 kWh

Table 2: Load for One Commercial Shop

Appliance	Power rating (W)	Quantity	Total Load (W)	Hours of Use	Total Power Consumption (Wh)
Actual Load Demand					
LED lights	20	1	20	6	120
Phone charging	15	1	15	6	90
Rechargeable Table Fan	30	1	30	14	420
Prospective/future Load Demand					
Fridge	107	1	107	24	2568
LED TV	40	1	40	8	320
TOTAL			**212**		**3518**

Different commercial shops had different load and energy consumption demands, hence, the total load demand and energy consumption for 150 commercial shops are as follow:

- Total load demand for 150 shops= 31,800 W
- Total energy consumption for 150 shops= 5,27,700 Wh = 527.7 kWh

Table 3: Load demand and energy consumption for one Cold Storage

Appliance	Volume	Temperature	Power rating (kWh)/ton	Container Quantity	Gross Weight	Total Power Consumption (kWh)
Cold Storage (For fish storage)	20 Feet/28 CBM	2 Degree Centigrade	70	1	30 Ton	2100
TOTAL			**70**			**2100**

The total load demand and energy consumption for one Cold Storage are as follow:

- Total load demand for one Cold Storage = 70 W/ton
- Total energy consumption for one Cold Storage = 2100 kWh

Table 4: Estimated Energy Consumption for The Area Selected

	Per Unit (kWh)	**Quantity**	**Total Consumption (kWh)/day**
Household	6.548	400	2,619.2
Shops	3.518	150	527.7
Cold Storage	2100	1	2100
Total			**5246.9**

So, monthly total power consumption for this community is, (5246.9×30) kWh **=** 1,57,407 kWh

And, yearly total power consumption for this community is, (157407×12) kWh = 18,88,884 kWh

Chapter 4: Result Analysis

4.1. Daily Solar Irradiation Calculation

At first, calculation is required to get the solar irradiation of the selected location by using the equations described in Chapter 2. A sample daily irradiation plot is shown in Fig. 4.1. The irradiation is calculated for a particular day, Dec 15, considering the tilt angle of 21.74^0 of the selected location. Figure shows that the maximum calculated solar irradiation during solar noon is 981 W/m². After that, daily cumulative energy is calculated by multiplying with time. For this day, the calculated daily cumulative energy is 6.67 kWh/m².

To get monthly energy, irradiation of each of the fifteenth days of the month has been considered. After that, it is multiplied with the number of days of the month; thus, monthly incident energy has been calculated. From Fig 4.2, the black bar chart shows the theoretically calculated monthly

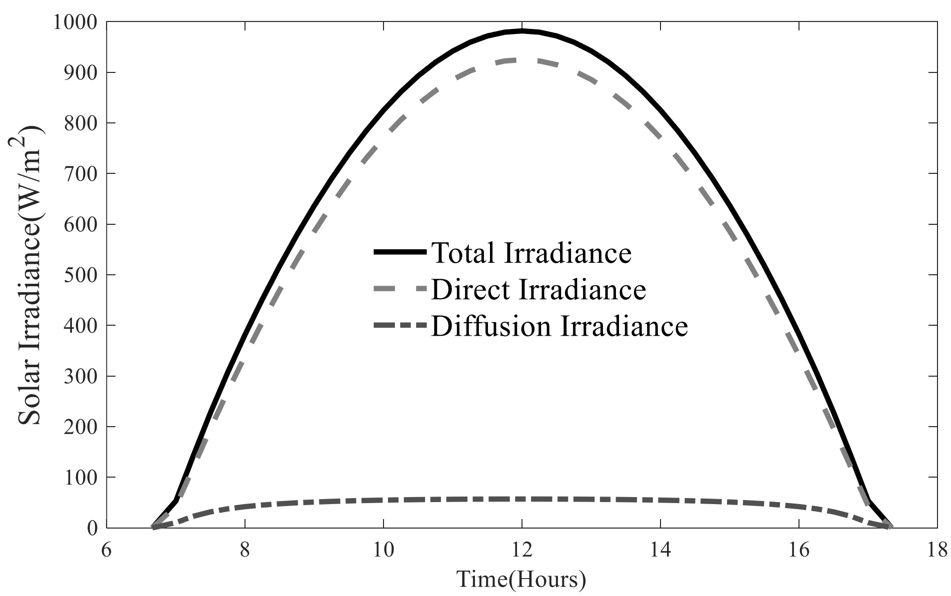

Figure 4.1 Daily Solar Irradiance calculated for December 15th

incident energy without considering cloudy days. However, to make the calculation more realistic, the cloudy day's impact has been considered.

Fig 4.2 indicates that July has the most calculated incident energy when considering clear days only; however, it has the least incident energy calculated considering cloudy days due to the rainy season. The highest cumulative monthly energy has been evaluated in March at 199.60 kWh/m^2, based on cloudy days, and the maximum has been estimated in July at 239.78 kWh/m^2, based on clear days. The total annual energy yield on cloudy days is 1.89 MWh/m^2, which is 29.93% less than the energy accumulated considering clear days only.

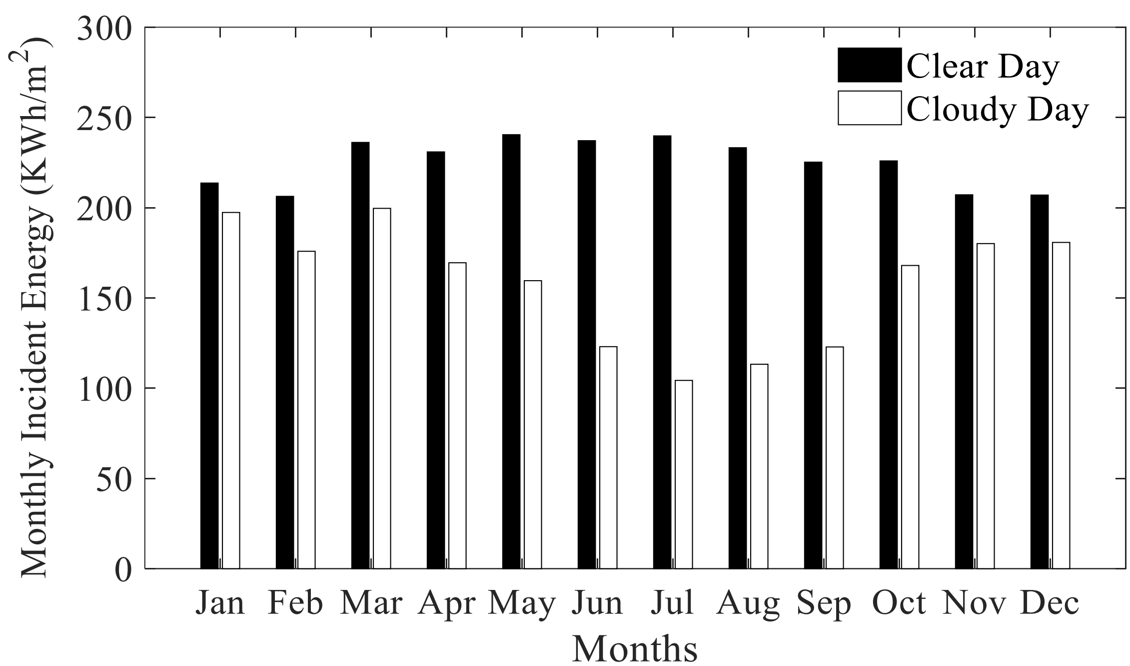

Figure 4.2: Monthly incident solar energy calculated considering only clear days and with cloudy days.

4.2. Scenarios To Analyze

At first, the daily average energy demand of the selected site (5246.9 kWh) has been calculated, and the total daily energy demand is to be met by solar and wind energy. The energy demand on solar and wind energy has been shared by using percentage-based scenarios. For calculating the number of PV panels, scenario analysis has been done from 10% to 90% energy shared by the solar energy. Similarly, to calculate the number of wind turbines, scenario analysis has been done from 90% to 10% energy shared by the wind energy. In scenario 1, 10% of load dependency on solar energy shares 524.69 kWh energy demand per day, and 90% dependency on wind energy shares 4722.21 kWh energy demand per day. Again, in scenario 2, 20% of load dependency on solar energy shares 1049.38 kWh energy demand per day, and 80% dependency on wind energy shares 4197.52 kWh energy demand per day. Similarly, the rest of the scenarios have been evaluated based on their relative significance (40%-60%; 50%-50%; 60%-40%; 80%-20%; 90%-10%). To find out the optimal sharing ratio between solar and wind, these cases are considered from where the required amount of solar panels, wind turbines, and batteries for the system can be calculated. The different ratios of solar and wind are directly responsible for the quantity of PV panels, batteries, and wind turbines needed, thus impacting the overall cost of the system. In Table 5, shared daily energy demand between solar and wind, varying from 10%-90% to 90%-10% is shown.

Table 5: Percentage wise distribution of Daily Energy

	From PV (Wh)	From WIND (Wh)
Scenerio 1(10-90)	524.69	4722.21

Scenerio 2(20-80)	1049.38	4197.52
Scenerio 3(40-60)	2098.76	3148.14
Scenerio 4(50-50)	2623.45	2623.45
Scenerio 5(60-40)	3148.14	2098.76
Scenerio 6(80-20)	4197.52	1049.38
Scenerio 7(90-10)	4722.21	524.69

4.3. Required Parameters Considered for Case Analysis

The system parameters for the proposed microgrid include a daily energy demand of 5,246.9 kWh, with energy shared between PV and wind systems ranging from 10%-90% to 90%-10%. Wind energy output is 172.5 kWh/day utilizing a 50 kW turbine with a 19.2 m rotor diameter, while solar insolation is calculated at 3.36 kWh/m², taking cloud impact into consideration. The battery system has an 80% depth of discharge, 90% utilization efficiency, and 60% PV energy storage at 48V. Average site wind speed is considered of 4.5 m/s. All the required parameters and respective values have been shown in Table 6.

Table 6: Required Parameters and Respective Values Considered for The Study

Required Parameters	Parameter Values Calculated/Considered
Calculated Daily Energy Demand	Daily Required Energy 5,246.9kWh
Percentage of Shared Daily Energy Demand Between PV-Wind	Solar 10% - Wind 90% to Solar 90% - Wind 10%
Solar Insolation Hour	Lowest Daily solar energy: 3.36 kWh/m^2 Solar Insolation hour has been chosen 3.36hr Considering cloud impact.
Calculated Daily Wind Energy	Wind Turbine chosen: 50KW Rotor diameter: 19.2 m Daily Wind Energy: 172.5 kWh/day
Battery and Wiring Efficiency	Battery Utilization Efficiency: 90% Wiring Efficiency: 98%
Battery Capacity	60% of PV energy will be stored in Battery

	PV system required voltage: 48V
Required Battery Charge Capacity	Temperature Correction Factor: 90% Depth of Discharge: 80%
Selected PV Modules and Batteries Rating	PV module – 250W (Vmax 30.6 V) Battery Capacity – 150Ah (12V) Number of Panel in series – 2 Nos Number of Batteries in Series – 4 Nos
Wind Speed	Average Wind Speed of the site: 4.5 m/s

4.4. Case-1: System with only Renewable sources (PV-Wind) and Batteries

Fig. 4.3(a) shows the required number of PV modules for a PV system array, as well as the battery storage that handles 60% of the designated PV system load dependency. The maximum number

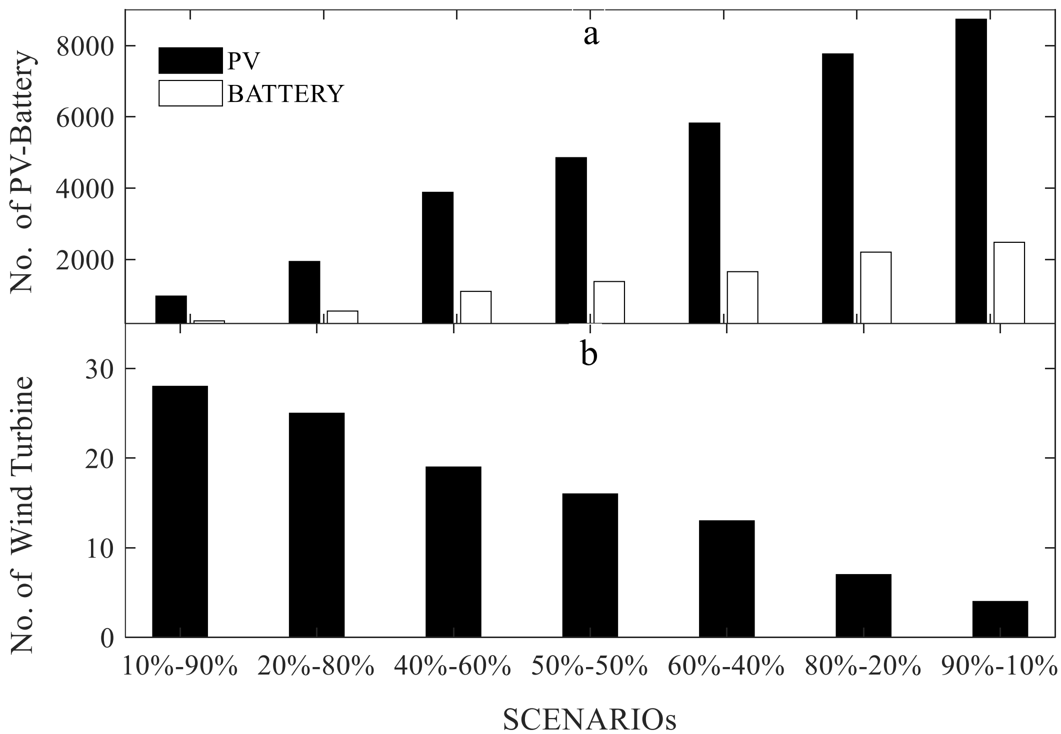

Figure 4.3: Estimated number of (considering non-renewable energy source). PV modules, batteries (a), and wind turbines (b)

of PV and battery with 90% load dependency listed in scenario 7 is 8736 and 2480, respectively. Correspondingly, Fig. 4.3 (b) depicts the required number of Wind Turbine system, with the maximum of 28 Wind Turbines required to satisfy the 90% load dependency as listed in scenario 1, and the minimum of 4 Wind Turbines required to meet the 10% load dependency.

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4.5. Life Cycle Cost Analysis for Case-1

Based on the theory of net present value described in Chapter 2, life cycle analysis of the Case 1 system with only renewable energy sources (PV-Wind) and batteries has been done. The estimated price and project life span is enlisted in table 7 considering 5.48% inflation rate [52] and 7% discount rate[53]. The scenario based net present value of the considered case for different scenerios is listed in table 8. In this study, 20 years of life cycle cost (LCC) analysis has been

Table 7: Estimated Cost of the Proposed System

Utilizing Parameter	**Estimated Cost (USD)**	**Estimated Life-Span (Year)**
250W Solar Panel	62.5	20
150Ah 12V Lead Acid Battery	150	5
50KW Wind Turbine	60000	20
Land Price (per Acre)	100000	
Grid Power Unit	0.12	
Inflation Rate, i	5.48	
Discount Rate, d	7.0	
Total Proposed System Investment	1907100 USD	

estimated where, 90% load dependency on wind energy is more viable, with a total system cost of $2034400 USD. Meanwhile, due to unreliable, antiquated data and geographical facets, this optimized ratio is now disregarded in this study [51]. Therefore scenario 2 has been considered as

Table 8: LCC Analysis of Case 1

Scenarios	Life Cycle Cost (USD)
Scenario 01	2034400 USD
Scenario 02	2122700 USD
Scenario 03	2299400 USD
Scenario 04	2388100 USD
Scenario 05	2476400 USD
Scenario 06	2650900 USD
Scenario 07	2739500 USD

the least cost which is **2122700** USD where wind energy has 80% load dependency and scenario 7 has the most which is 2739500 USD life cycle cost where PV system has been allocated for 90% load dependency.

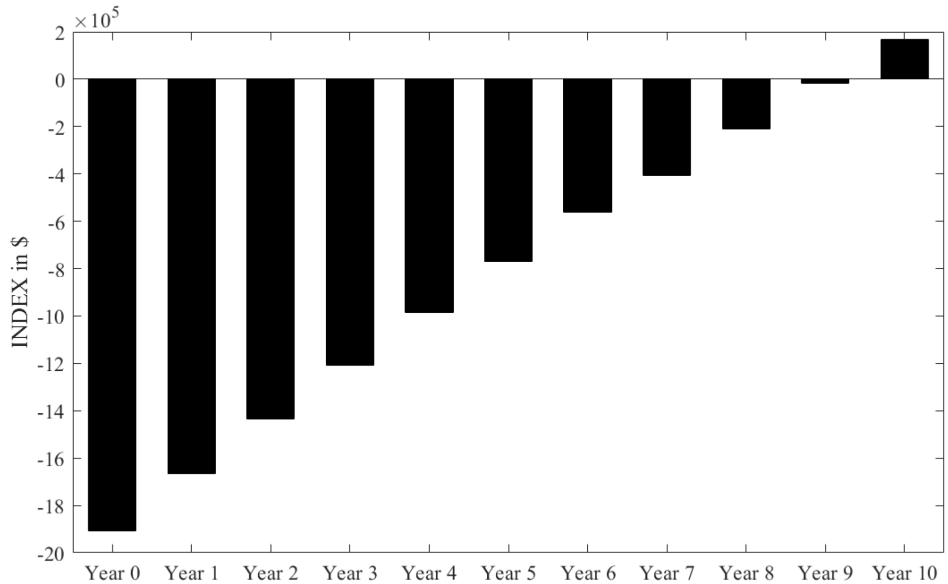

Figure 4.4: Capital investment and payback time of the proposed system considering renewable sources with battery storage

4.5.1 Payback Calculation for Case 1

According to the LCC analysis and other considerations, scenario 2 is the best possible choice for this microgrid system because it has the least cost and land area (Scenario 2 is the best alternative for this microgrid system since it has the lowest cost and land usage (roughly 3.2 acres) compared to the other four scenarios. So, the approach to designing the microgrid system will be based on scenario 2. The energy payback period has been assessed for scenario 2, where there are 1942 PVs, 552 batteries, and 25 wind turbines. Moreover, the payback period has been calculated based on a five-year battery replacement period for a project that will last 20 years. Fig. 4.4 needs to be observed to assess the energy payback period of the proposed microgrid system. This work has a payback duration of 9.09 years following the initial investment of around 1907100 USD. Total cost analysis related factor values has been listed in Table 9.

Table 9: Estimated present value of The System considering only renewable sources with battery storage

Number of Year	Present Worth Factor	Present Worth Cost of Proposed System for Battery Maintenance	Present Value of the System (as per Local Unit Tariff)
0	1	1661550	240048
1	0.9813084112	0	249744.8019
2	0.9629661979	0	259838.727
3	0.9449668297	0	270346.291
4	0.9273038983	0	281284.7079
5	0.9099711152	0	292671.9205
6	0.8929623093	71762	304526.6312
7	0.876271425	0	316868.335
8	0.8598925199	0	329717.3538
9	0.8438197625	0	343094.8718
10	0.8280474305	0	357022.9731
11	0.8125699084	77084	371524.6802
12	0.7973816858	0	386623.9951
13	0.7824773553	0	402345.9411
14	0.7678516103	0	418716.6076
15	0.7534992437	0	435763.1958
16	0.7394151457	66808	453514.0676
17	0.7255943019	0	471998.7952
18	0.7120317916	0	491248.2145
19	0.6987227861	0	511294.4793

4.6. Case-2: System with Renewable sources (PV-Wind) with backup generators and Batteries

The average daily insolation hour for the month of April has been taken into consideration (5.6 hours), which is almost the average daily insolation hour for the entire year, in order to evaluate non-renewable energy sources and also to limit the massive amount of PV panel sources. As a result, even though a small amount of excess energy over the load demand could be generated

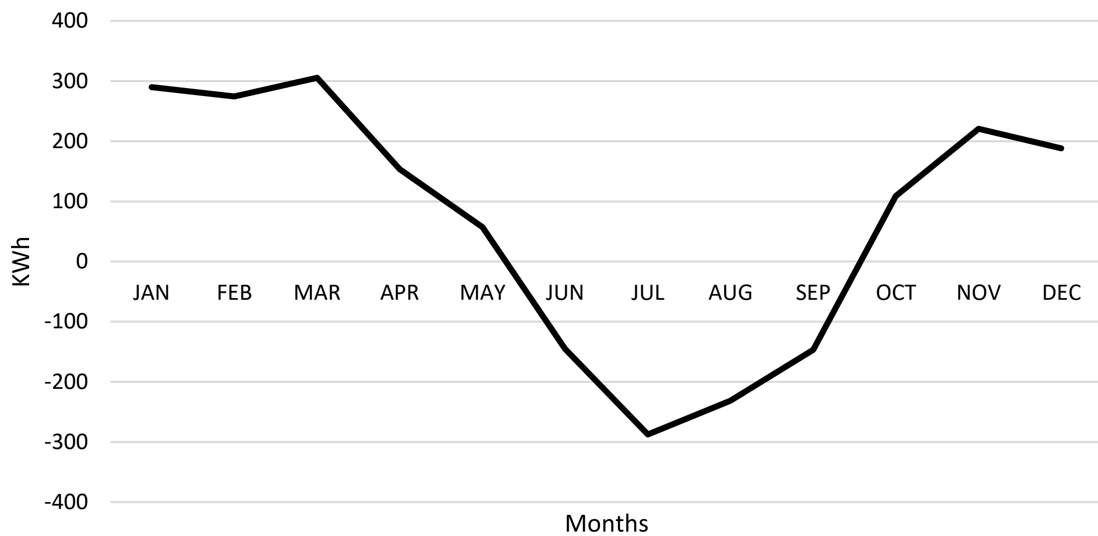

Figure 4.5: Renewable energy system electrical output analysis. Excess energy from the system (a), Less energy from the system (b).

from renewable sources, it has been necessary to use a backup power source from June to September because the same number of PV sources are unable to generate enough energy due to the lowered solar insolation hours during these months. In March, standalone PV and wind power systems produced 5.8% more output energy than the load requirement; however, in July, 5.48% more energy is required to be produced externally, which is covered by a diesel generator in this study.

4.6.1. Case-2 analysis

Study has been undertaken, this time using a nonrenewable energy system supported by a diesel generator. The diesel generator will serve as a backup power supply for the PV system; hence, the number of PV and batteries can be significantly decreased. the seven scenarios with the diesel generator sharing the load requirement, which is unable to be covered by the PV source as the few days have lower insolation hours than expected in this particular investigation. Based on thumb rule, 0.4 liters diesel is consumed to generate 1kWh energy by the generator. Thus, in scenario 02(20%-80%) 1166 PV modules, 552 batteries, and 324.53 liters of diesel are required for the generator to meet 20% of the PV source's load requirement. Moreover, in scenario 07(90%-10%), the diesel generator has been estimated to contribute larger portion of the PV-based load requirement. Thus, 5242 PV modules, 2480 batteries, and 2068.56 liters of diesel are required for the generator to meet the PV source's load demand requirement. Figure 4.6 shows the number of panels, wind turbines and batteries with the diesel consumption. Similarly, the remaining possibilities were analyzed based on their relative relevance and 20 years of life cycle cost (LCC)

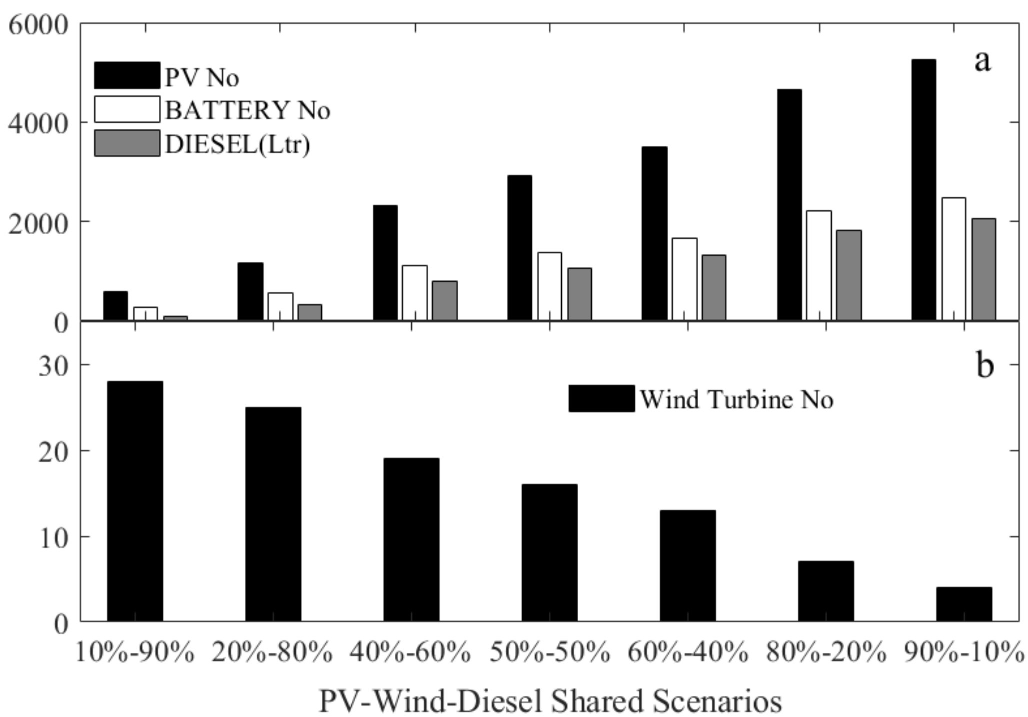

Figure 4.6: Estimated Shared Daily Load Demand (considering non-renewable energy source). PV modules, batteries, diesel (a), and wind turbines (b)

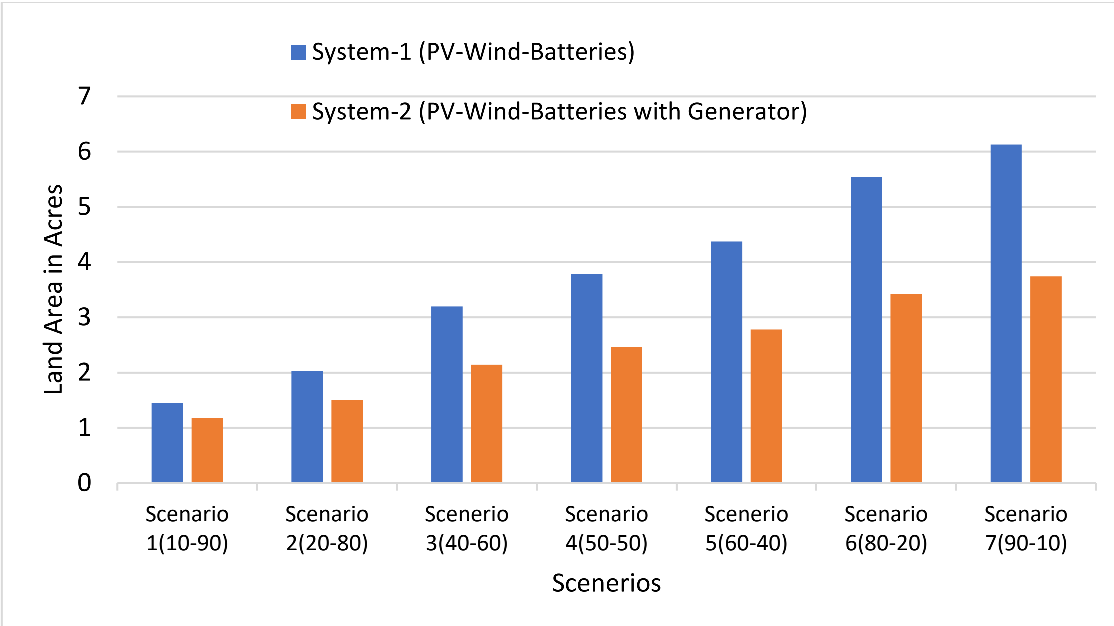

Figure 4.7: Estimated land requirement in acre for PV, wind and batteries.

analysis has projected that scenario 1(10%-90%), has the lowest cost at 2029300 USD, where PV systems have been allocated for 10% load dependency and diesel generators have also shared of it, while scenario 7, has the highest cost at 3046100 USD, where PV systems have been allocated for 90% load dependency. However, on the whole, the LCC is quite a bit lower than the cost of an island-based PV and wind turbine system. Based on current market price, 1.09USD/Liter diesel price has been considered. Thus, it is proposed that the project be initiated with a focus on shared non-renewable sources and subsequently converted into a full islanded microgrid system consisting of PV and wind power gradually over time. After considering cloud impact and other efficiency parameters, the optimized scenario-based system produces 2000.44 MWh/year, or 5.48 MWh/day, which is 4.44 % more than the required daily load. Also, based on a 20-year project life, the return on investment is expected to be 6.27 years.

From Figure 4.7 it is seen that increasing the PV panel numbers increases the land area requirements. Here scenario 2 requires 1.5 acres of land area for the PV panels set up, wind turbine set up and battery integration when backup generator considers. But it requires 2 acres of land without generator. Scenerio 6 shows the value is above double from scenario 2 as the number of panel increased.

Chapter 5: Conclusion

The study looks at the energy needs of Dublar Char, an isolated island that requires 5,246.9 kWh per day to run 150 mini-local businesses, 400 residences, and a sizable cold storage facility. It was suggested to use an optimal hybrid microgrid system that combined independent wind and photovoltaic systems. The optimal method distributes 80% of load to wind energy and 20% to PV with battery storage. This arrangement requires about 2 acres of land and generating 5.48 MWh per day, which is 4.44% more than the daily requirement to allow for generation variability. However, the ROI would be a little longer at 9.09 years. After considering the backup diesel generator, For this configuration, a 20-year return on investment (ROI) of 6.27 years is estimated via lifecycle cost (LCC) analysis. The system produces 2,000.44 MWh annually. This alternate scenario keeps the island's power dependable while offering more flexibility as well as reduces the land area to 1.5 acres..

In this study, two separate case have been considered to meet the daily estimated demand of the island. System 1 only comprises with the PV and wind energy sources and system 2 incorporates the backup disel generator with the renewable sources. After calculating the irradiations of the site and consider wind speed and other parameters, it is found that 20% of the daily demand from PV and 80% demand from wind turbine is the optimum design as it requires less land and return on investment is less. Also, to make it more convenient, backup diesel generator based system helps to reduce the life cycle cost and payback time. In future work, technical design of the micro grid considering converters and management system will be studied.

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