DESIGN, OPTIMIZATION AND FEASIBILITY ANALYSIS OF A GRID-CONNECTED MICROGRID IN ASHULIA

A Project report is submitted in partial fulfillment of the requirements for the award of Degree of Bachelor of Science in Electrical and Electronic Engineering.

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DECLARATION

We hereby declare that this project **"DESIGN, OPTIMIZATION AND FEASIBILITY ANALYSIS OF A GRID-CONNECTED MICROGRID IN ASHULIA"** represents our own work which has been done in the laboratories of the Department of Electrical and Electronic Engineering under the Faculty of Engineering of Daffodil International University in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical and Electronic Engineering, and has not been previously included in a thesis or dissertation submitted to this or any other institution for a degree, diploma or other qualifications. We have attempted to identify all the risks related to this research that may arise in conducting this research, obtained the relevant ethical and/or safety approval (where applicable), and acknowledged our obligations and the rights of the participants.

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APPROVAL

The project entitled **"DESIGN, OPTIMIZATION AND FEASIBILITY ANALYSIS OF A GRID-CONNECTED MICROGRID IN ASHULIA"** submitted by **Ibrahim Hossen (193-33-1025),Ratul Hasan (193-33-1031) & Md Bakibullah (193-33-1016)** has been done under my supervision and accepted as satisfactory in partial fulfillment of the requirements for the degree of **Bachelor of Science in Electrical and ElectronicEngineering** in **January, 2024.**

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Dedicated

To

Our Parents and Faculty Members

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LIST OF ABBREVIATIONS

RES	Renewable Energy Source
HOMER	Hybrid Optimization of Multiple Energy Resources
PV	Photovoltaic
BG	Biogas Generator
LCOE	Levelized Cost of Electricity
NPV	Net Present Value
BPDB	Bangladesh Power Development Board
NPC	Net Present Cost
REF	Renewable Energy Fraction
GHG	Green-House Gas

LIST OF SYMBOLS

Symbol	*Name of the symbol*
i	Annual Interest Rate
$C_{ann,tot}$	Total annualized expense
R_{proj}	Project Lifetime
CRF(.)	Capital-recovery factor
$C_{NPC,tot}$	Total Net Present Cost

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ABSTRACT

This thesis book explains a detailed study of how renewable energy can be used in Bangladesh's power system to solve energy problems and make the most of clean energy sources. We're interested in this because we want to see if it makes financial sense to connect renewable energy systems to the power grid.

In the background, where people use about 128.19 kWh of electricity every day and the most electricity used at one time is 21.91 kW, we're looking into using sunlight and waste from cows (cow dung) to make electricity. The sunlight here is pretty good, with an average clearness index of 0.521 and 4.65 kWh of sunlight per square metre every day. We're also thinking about the cow dung, which can be used to make electricity.

We thought about different ways to set up these systems, and the best way we found is to use a 50 kW solar panel system with a 20 kW inverter, a 48V battery setup, and a 5 kW biogas generator. We came up with four different plans: using both solar and biomass, only solar, solar with batteries, and only biomass.

Economically, the plan with both solar and biomass is really promising. We found that you can get back about 30.81% of the money you put in during the first year. It takes about three years and three months to get all your money back. Over the whole time this system works, you end up making about 7.69 times the money you put in.

In the end, we want to show that using renewable energy in Bangladesh's power system is a great idea. The plan we recommend with both solar and biomass is not only good for the environment, but it also makes a lot of sense from a practical and financial perspective.

Keywords: PV, RES, HOMER Pro, Optimization, GHG, COE, NPC, REF

CHAPTER 1
INTRODUCTION

1.1 Background

Energy is regarded as being a key factor in attaining a nation's ambitions for economic and social prosperity [1]. Energy is essential for improving people's living situations since it is needed for the manufacture of various goods that are necessary for everyday life as well as electricity, cooking, cooling, and heating. The growing energy consumption of the twenty-first century is inevitable. The number of known and suspected environmental risks would climb as a result of this increase in demand. By 2060, it is anticipated that the world's need for electricity will have increased by 50%, and it is anticipated that non-conventional sources will have a significant impact on the production of energy on a worldwide scale [2].

Energy is a growth and innovation driver in the field of economic development. Industries may thrive when they have access to inexpensive, dependable energy, which boosts productivity and competitiveness on a national and international level. Energy is crucial for the smooth operation of manufacturing processes, agriculture, and infrastructure development, which promotes economic diversification and opens up millions of job possibilities. A further benefit of adopting energy-efficient practices is that they can lower manufacturing costs and allocate resources to R&D and growth, encouraging innovation and technological improvement.

Energy is essential for a person's quality of life and overall well-being in the context of social development. Modern living is made possible by electricity, which enables access to clean water, sanitation, healthcare, education, and communication [3]. With electricity, healthcare institutions can run vital medical equipment, schools can provide better educational materials through technology, and communities can connect with the rest of the world online, reducing isolation and promoting inclusiveness. People's living standards can be raised by reliable energy supply, helping them to escape poverty and enhancing societal circumstances generally.

In developing nations, energy is a critical enabler for social equity and poverty alleviation [4]. Lack of power is sometimes equated with little chances, which impedes advancement in health, education, and economic development. Countries may empower marginalized populations, particularly those in rural and isolated locations, and facilitate their incorporation into the larger socioeconomic fabric by bridging the energy divide. Access to electricity has substantial positive effects on women and girls because it lessens the stress of manual labor, increases safety, and expands educational options.

In addition, guaranteeing stability and resilience in the face of external shocks and disruptions, energy security is a crucial component of national growth [5]. Researchers and international organizations, including the United Nations (UN), International Energy Agency (IEA), International Atomic Energy Agency (IAEA), and World Bank, have given considerable attention to the complex issue of energy poverty in developing countries. Energy-producing nations that invest in domestic energy production and diversify their energy sources are better able to endure changes in the world energy markets, protecting their economic interests and promoting energy independence.

The globe has been plagued by the complex and diverse problem of the global energy crisis for many years. The demand for energy has increased dramatically due to a growing global population and fast industrialization in developing nations. The International Energy Agency (IEA) recently released data showing that the world's energy consumption has increased by 24% over the past two decades and is expected to climb by another 10% by the year 2040 [6]. The United States Geological Survey (USGS) conducted research that showed that the proved oil reserves have been falling at a pace of around 1.4% per year [7]. In addition, a lot of oil-producing countries are having trouble maintaining production levels because of geopolitical instability and infrastructure problems. The increasing global demand for energy, coupled with growing environmental concerns and the imperative to mitigate climate change, has led to a pressing need for the widespread adoption and integration of renewable energy sources into the grid. Grid-connected renewable energy systems play a pivotal role in achieving a sustainable and resilient energy infrastructure. However, despite significant advancements in renewable energy technologies, numerous challenges and barriers hinder their seamless integration into the global energy mix. This thesis aims to identify, analyze, and propose solutions to the key issues associated with grid-connected renewable energy systems, with a particular focus on their impact on the evolving global energy mix. The global energy mix refers to the combination of different energy sources utilized to meet the world's energy needs. As per the data in September 2021, the global energy mix has been dominated by fossil fuels, accounting for approximately 80% of the total energy consumption [8]. The following "fig. 1.1" illustrates the global energy mix.

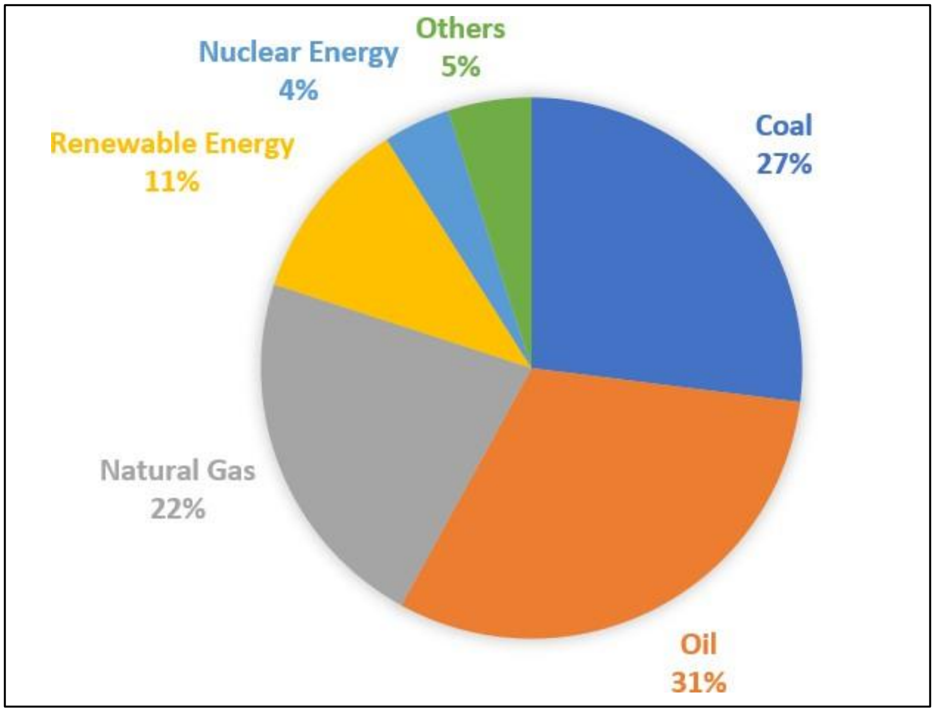


Fig. 1.1 Global Energy Mix

1.2 Problem Statement

In Bangladesh, the limited utilization of renewable energy sources within the grid highlights the urgent need for grid-connected microgrid solutions to promote sustainability, energy access, and resilience. In the context of Bangladesh, a country heavily reliant on traditional energy sources, the underutilization of renewable energy remains a significant and pressing challenge. With a mere 2% of electricity generation harnessed from renewable sources, the nation finds itself at a critical crossroads. This dearth of renewable energy integration not only undermines efforts to mitigate climate change but also exacerbates issues of energy security, high electricity costs, and an unstable power supply. Consequently, there is an urgent need to develop and implement grid-connected microgrid solutions to enhance the integration of renewable energy sources, improve energy access, and promote sustainability. This research seeks to address these multifaceted issues by investigating the technical, economic, and regulatory aspects of grid-connected microgrids within the unique socio-economic and environmental context of Bangladesh, aiming to pave the way for a more sustainable and resilient energy future.

Bangladesh's potential for sustainable energy is indeed excellent, particularly due to its abundant solar energy resources. The installed capacity of renewable energy in Bangladesh, as indicated in "Table 1.1," exemplifies the country's progress in embracing renewable energy technologies, The table presents data on the capacity of different renewable energy technologies in both off-grid and on-grid settings, as well as their total capacities in megawatts (MW). It outlines the following technologies and their respective capacities: solar (960.71 MW total, with 366.07 MW off-grid and 594.64 MW on-grid), wind (2.9 MW total, with 2 MW off-grid and 0.9 MW on-grid), hydro (230 MW on-grid with no off-grid capacity), biogas to electricity (0.69 MW off-grid and no on-grid capacity), and biomass to electricity (0.4 MW off-grid and no on-grid capacity). In total, the combined renewable energy capacity amounts to 1194.7 MW, with 369.16 MW designated for off-grid applications and 825.54 MW for on-grid use. This data highlights the significant contribution of solar energy to the overall renewable energy capacity, while also illustrating the diversity of technologies in the energy mix.

However, as the thesis delves into the challenges and opportunities in grid-connected renewable energy systems, it is imperative to recognize that despite the growth in renewable energy capacity, traditional non-sustainable energy sources continue to be used in conjunction with environmentally friendly electricity sources. This underscores the complex reality where the transition to sustainable energy sources faces various hurdles, including intermittency, infrastructure constraints, and policy issues, similar to the global energy mix challenges.

Moreover, the specific case of Bangladesh, with its mixed energy portfolio, highlights the importance of addressing these challenges in a way that is tailored to the unique energy landscape of each country. The thesis can explore how innovations in solar-powered technologies, which have already shown promise in Bangladesh's context, can not only contribute to reducing the country's dependence on traditional energy sources but also play a significant role in providing electricity to remote and underserved areas, where access to the grid and social safety nets may be delayed.

By examining these issues in the context of Bangladesh's renewable energy capacity and the specific challenges it faces, your thesis can contribute valuable insights and recommendations that are not only relevant at a global scale but also address the practical challenges and opportunities in a country that has made significant strides in embracing renewable energy technologies.

Bangladesh's potential for sustainable energy is excellent, thanks in large part to energy derived from the sun. Whatever the case, traditional non-sustainable energy sources will continue to be used together with environmentally friendly electricity for years to come. In any case, solar-powered innovation can play a big role in rescuing customers who reside outside the public sphere or in places where access to the social safety net is delayed.

Table 1.1 Renewable Energy Installed Capacity in Bangladesh [9]

Technology	Off-grid (MW)	On-grid (MW)	Total (MW)
Solar	360.07	594.64	960.71
Wind	2	0.9	2.9
Hydro	0	230	230
Biogas to Electricity	0.69	0	0.69
Biomass to Electricity	0.4	0	0.4
Total	**369.16**	**825.54**	**1194.7**

1.3 Objectives

The main goals of this substantial thesis are the following:

The primary goal of this research is to conduct a feasibility study and optimize the design of a microgrid system in Ashulia, Khagan Dhaka, integrating solar and biomass resources. The aim is to harness the local solar and biomass potential to generate electricity, ultimately achieving self-sufficiency and cost effectiveness in the area's power supply.

- Analysis of the Literature on Grid-Connected Systems.
- To Determine Residential Load Requirements.
- To Design and Optimize Grid-Connected Systems.
- To Feasibility Analysis of the Proposed System.
- Economic and Environmental Analysis of the Optimization Systems.

1.4 Technologies for Grid Connected Microgrid

A grid-connected microgrid represents an advanced and versatile energy solution that seamlessly blends the benefits of both local autonomy and external power exchange [10]. This innovative system operates as a self-sufficient, localized energy network, capable of generating, storing, and distributing electricity within its confines, catering to the specific needs of the local community it serves.

The beauty of this modern marvel lies in its bi-directional power flow capabilities, which allow it to dynamically interact with the main power grid. In times of surplus energy generation within the microgrid, it can generously share its excess power with the external grid, bolstering the overall grid's stability and resilience. On the other hand, during periods of high demand or insufficient local generation, the microgrid can intelligently draw power from the external grid, ensuring a consistent and uninterrupted supply for its inhabitants.

Moreover, the grid-connected microgrid's energy exchange is a harmonious dance of collaboration and sustainability. It actively engages in energy balancing, adjusting its power output and consumption in real-time to complement the external grid's requirements, thus promoting energy efficiency and reducing waste.

The significance of such a system cannot be overstated, as it revolutionizes the conventional energy landscape by offering a decentralized approach to power generation and distribution. This decentralization fosters energy independence for local communities, reducing their dependence on centralized power plants and long-distance transmission lines, thereby enhancing energy security and mitigating the risk of widespread blackouts.

Furthermore, a grid-connected microgrid serves as a beacon of renewable energy integration. By integrating various renewable energy sources like solar panels, wind turbines, and even small-scale hydroelectric generators, it harnesses the power of nature and converts it into a sustainable and environmentally friendly power source. The surplus energy can then be shared with the larger grid, effectively increasing the overall share of renewable energy in the electricity mix, fostering a greener and more sustainable future for all.

As the world moves towards a cleaner and more sustainable energy landscape, the grid-connected microgrid stands as a shining testament to the potential of localized energy solutions. Its adaptability, reliability, and green credentials make it a viable and forward-thinking choice for powering communities and industries alike, ushering in an era of smarter, interconnected, and eco-conscious power systems for generations to come.

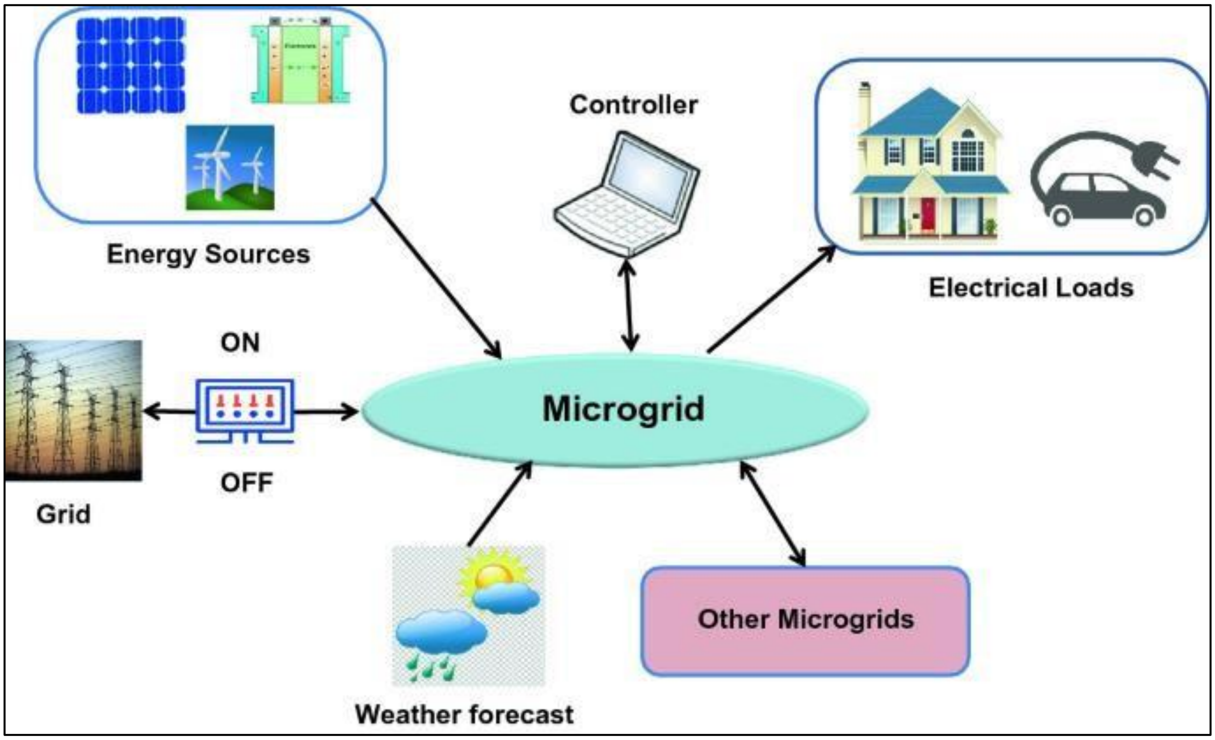


Fig. 1.2 Architecture of microgrid [11]

1.5 Implementation Schedule

Table 1.2 depicts "Thesis Project Implementation Schedule and Timeline" which conveys the purpose of the chart, indicating that it's a visual representation of the project's planned activities, their dependencies, and their durations over time. It serves as a roadmap for the execution of your thesis, providing a clear and organized overview of the key steps in your research journey.

Table 1.2 Thesis Project Implementation Schedule and Timeline

SL	Task/Activity	Duration (Approximately)	Dependencies
01	Define Thesis Scope and Objectives	1 week	No dependencies
02	Literature Review	5 weeks	Task 1
03	Data Collection and Preparation	6 weeks	Task 1 and 2
3.1	Gather technoeconomic data	3 weeks	Task 1 and 2
3.2	Organize collected data	3 weeks	Task 1 and 2
04	Simulation Setup	5 weeks	Task 3.
05	HOMER Pro Load Calculation	4 weeks	No dependencies
06	Simulation and Optimization	3 weeks	Task 3, 4 and 5
07	Results Analysis	6 weeks	
7.1	Initial capital and COE analysis		

7.2	Annual electricity generation analysis	4 weeks	Task 6
7.3	GHG reduction analysis		
7.4	Comparison by using bar graphs	2 weeks	Task 7.1 to 7.3
08	Proposed System	5 weeks	Task 7
8.1	Select the Most Optimized System	2 weeks	Task 7
8.2	Profit Calculation and Grid Comparison	3 weeks	Task 7
09	Thesis Writeup and Documentation	10 weeks	Task 1 to 8
10	Review and Editing	11 weeks	Task 11
	Total	57 Weeks	

1.6 Structure of the Report

The remaining thesis paper is structured in the following way: Chapter 2 covers the literature review, which includes background information, a review of related research, and a comparative analysis of previous studies, providing the framework for the research that follows. In Chapter 3, the study's materials and methodologies are detailed, including explanations of HOMER Pro optimization, load calculations, system design, and system analysis. Chapter 4 presents the results, followed by a discussion of the capabilities, constraints, and performance of grid-connected energy systems, shedding light on the broader context of sustainable energy generation and environmental impact. Chapter 5 delves into project management, offering insights into tasks, timetables, milestones, resources, and cost management, all with graphical representations for clarity. Chapter 6 focuses on the project's impact assessment, covering economic, sociological, global, environmental, ethical, and comparative elements to ensure a comprehensive evaluation. Finally, Chapter 7 concludes the thesis by summarizing the study's findings and providing suggestions for further research and practical applications in grid-connected energy systems.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

A major and pressing concern of contemporary society is the incorporation of renewable energy sources into the electrical grid. The main forces behind this are the need for workable and sustainable energy solutions, the requirement to assure energy security, and the convergence of global concerns about climate change. Grid-connected renewable energy systems are playing a bigger role in tackling these pressing issues as a result of the concerns listed above. This study of the literature covers the fundamentals of this change, the intricate challenges it presents, and the significant new innovations that have impacted the grid-connected renewable energy market.

It is imperative that renewable energy sources be integrated into the electrical system. Unchecked greenhouse gas emissions into the atmosphere are the primary driver of climate change, which is spreading and has major effects on both human society and the environment. The increasing frequency of extreme weather events, the trend towards global warming, and the increasing threats to ecosystems demand a quick and decisive switch to energy sources that release fewer greenhouse gases into the atmosphere. This means that all strategies for distributing, managing, and using electric power need to be completely reevaluated in addition to altering the way energy is created.

At the same time, there has been an increase in focus on the topic of energy security. Because of their reliance on fossil fuels and the centralization of power generation within systems, countries are susceptible to disruptions in their energy sources and geopolitical conflicts. Improved energy security is a result of grid-connected renewable energy systems' increased resilience of the energy infrastructure, encouragement of a diversity of energy sources, and less reliance on finite and politically fragile resources.

The goal of this review of the literature is to offer a thorough understanding of the intricate field of grid-connected renewable energy. This paper examines the many aspects that are involved in the effective integration of renewable energy sources into the electrical grid. Technological developments, societal variables, and legal frameworks are some of these elements. The analysis of grid stability, environmental effects, and economic feasibility reveals how complex and interconnected the factors are, necessitating careful assessment.

This study also highlights how dynamic the profession is, given how fresh findings and advancements are always changing its direction. There is research available on topics that are only beginning to gain popularity yet have the potential to change the grid significantly in the future. Sector coupling, distributed energy resources, and grid digitization are some of these subjects. It is more crucial than ever to have complete knowledge and make informed judgements in this rapidly changing environment.

2.2 Related Research

In these comprehensive reviews, it is evident that each one contributes valuable and distinct insights into the world of microgrid systems. The common thread among them is a strong focus on the integration of renewable energy sources and their significant impact on cost-effectiveness and sustainability. Together, these studies collectively underscore the tremendous potential of microgrids in enhancing energy reliability, reducing operational costs, and mitigating environmental concerns.

The paper authored by AK Raji and DN Luta, titled "Modelling and Optimization of Community Microgrid Components," delves into the technical and economic aspects of a microgrid within a housing estate [12]. The study meticulously calculates the levelized cost of energy for an off-grid community microgrid, which is estimated at approximately US$0.506. Furthermore, the paper conducts a thoughtful comparison between the off-grid microgrid configuration and a grid-connected backup energy system. Notably, it underscores that the economic viability of the off-grid microgrid diminishes when the breakeven distance is under 130.84 km. While the research provides valuable insights into various microgrid configurations' cost-effectiveness, a more exhaustive examination of the methodology and practical implications would elevate its significance in the realm of energy infrastructure planning and management.

In "Microgrid for All India Institute of Medical Sciences" by C Palanichamy and P Naveen, the authors put forth an innovative proposal for a microgrid system catering to the needs of the New All India Institute of Medical Sciences (AIIMS) in Madurai, India [14]. The microgrid design seamlessly integrates renewable energy sources, including photovoltaic and wind turbine systems, in conjunction with a reliable backup from a diesel generator and energy storage. The primary objective is to ensure a secure and dependable electricity supply for this critical healthcare facility. Importantly, the paper underlines the compelling returns on investment and the attractive levelized cost of energy. It also underscores the environmental benefits, particularly the reduction in carbon emissions compared to heavy reliance on the utility grid.

In "Techno-economic Design and Evaluation of a Small Community-Based Microgrid" by VK Garg and S. Sharma, the research zeros in on a microgrid designed for a small community that remains interconnected with the utility grid [15]. This microgrid is designed to accommodate a blend of renewable energy sources. Notably, the study highlights the remarkable cost-effectiveness of this microgrid configuration and the positive influence of net-metering facilities on its sustainability. It underscores a significant reduction in the cost of energy, along with a substantial contribution from renewable energy sources, making it a practical and sustainable solution for similar small communities.

The paper "Optimal Design and Techno-economic Analysis of a Microgrid for Community Load Applications" by V. Boddapati and SA Daniel is all about making the best microgrid for the BMS College of Engineering in Bengaluru, India [16]. The microgrid's composition is diverse, featuring an array of renewable energy sources, energy storage, and a dependable diesel generator to ensure a robust power supply. The research makes use of economic yardsticks like the levelized cost of energy and net present cost to thoroughly evaluate the microgrid's performance, both when it operates autonomously and when connected to the grid. The findings strongly indicate that the designed microgrid not only proves to be cost-effective but also showcases superior sizing in comparison to earlier models.

"Techno-economic Feasibility Analysis of Grid-Connected Microgrids" by DM Mahmud, S Hasan, and SMM Ahmed underscores the paramount importance of optimizing the size of hybrid renewable energy systems [17]. Employing the Hybrid Optimization Multiple Energy Resources (HOMER) software, the research introduces an exemplary grid-connected hybrid power system. This design significantly reduces operational costs and lessens the environmental impact. Importantly, the paper underscores the overall viability and cost-effectiveness of delivering power through a microgrid, leading to a notable reduction in the levelized cost of energy and operational costs.

Finally, "Design and Implementation of an Islanded Hybrid Microgrid System for a Large Resort Centre" by SKA Shezan, Rawdah, SS Ali, and Z Rahman looks into how to best use the extra energy that an islanded hybrid microgrid system produces, focusing on the Penang Hill Resort in Malaysia [18]. Using HOMER Pro software, the study carefully finds the best combinations of the system's parts. It also shows that the system is cheap, doesn't release much carbon, and makes good use of extra energy by using an electric heater as a diversion load.

2.3 Compare and Contrast

Through an extensive review of various prestigious journal articles and conference papers, we fully analyzed a number of grid-connected microgrids for our in-depth study, illustrated in "table 2.1." Our investigation concentrated on a number of important factors, such as the complex system architectures utilized in these microgrids, the assessment of energy prices, and the calculation of the proportion of renewable energy in each system.

Table 2.1 Literature Review

SL	Structure of the System	Type	Renewable Fraction (%)	COE ($/kWh)
01	PV-Diesel Generator-Battery [12]	Off-grid	–	0.506
02	PV- Diesel Generator-Wind Turbine [13]	Off-grid	99	0.651
03	PV- Diesel Generator [15]	Off-grid	98.90	0.631
04	PV- Diesel Generator-Battery [14]	On-grid	17.36	0.078
05	PV- Wind Turbine-Diesel Generator-Battery [12]	On-grid	25.04	0.075
06	PV- Wind Turbine-Battery [15]	On-grid	64.80	0.047
07	PV- Battery [17]	On-grid	64.80	0.045
08	PV-Wind Turbine [16]	On-grid	–	0.053
09	PV-Wind Turbine-Diesel Generator [18]	Off-grid	–	0.319
10	PV-Battery [17]	On-grid	67.70	0.034
11	PV [17]	On-grid	67.70	0.021
12	PV-Diesel Generator-Wind Turbine-Battery [18]	Off-grid	27.80	0.165

2.4 Summary

The reviewed papers cover a diverse range of microgrid implementations. One paper assesses the feasibility of a housing estate microgrid from technical and economic perspectives. Another proposes a microgrid solution to ensure a reliable electricity supply for a medical facility. A third paper examines a small community-based microgrid, emphasizing its cost-effectiveness. The fourth paper concentrates on the design of a community-level microgrid for an educational institution, showcasing both cost-effectiveness and superior sizing. The fifth paper explores the techno-economic feasibility of grid-connected microgrids, underlining the importance of optimizing the sizing of hybrid renewable energy systems.

CHAPTER 3
MATERIALS AND METHODS

3.1 Introduction

We have used HOMER Pro software for the design and simulation. HOMER Pro (Hybrid Optimization of Multiple Energy Sources) is a software tool for microgrid design and optimization [19]. It is a user-friendly software used to plan and optimize energy systems, especially those using renewable sources. It helps people figure out the most cost-effective way to generate, store, and use energy. This software is essential for designing clean and sustainable energy solutions, whether it's for a small village or a big city, by considering factors like costs, available resources, and financial feasibility.

Fig:2.1 Rahat villa, Ashulia, Dhaka

The HOMER algorithm uses a combination of heuristics and mathematical optimization to find optimal solutions. “Fig. 3.1” depicts the overall optimization process of the HOMER.

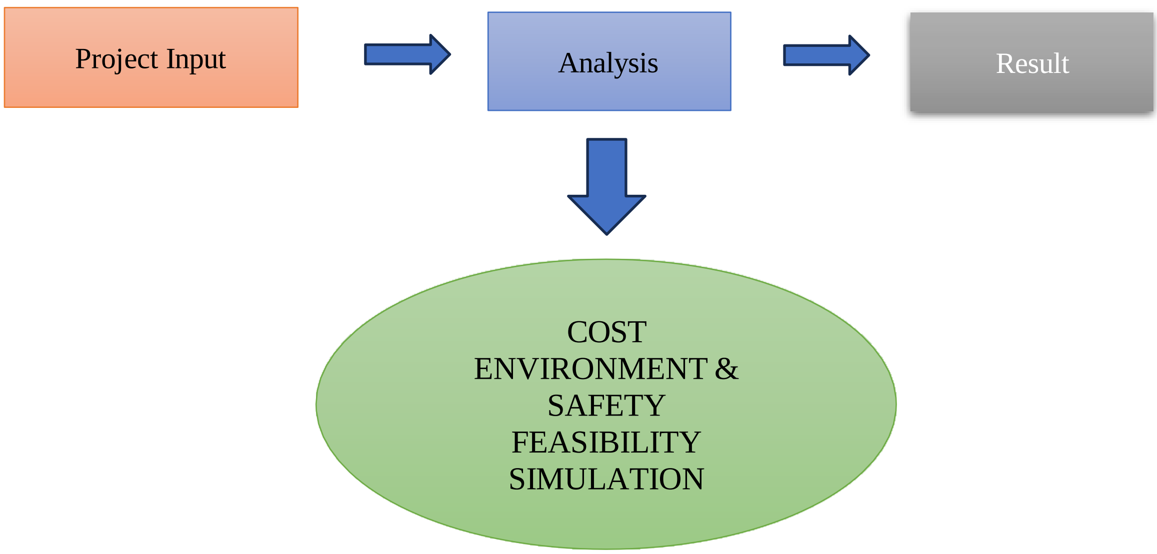


Fig. 3.1 HOMER Pro Optimization [20]

We carried out our case study at a residential building in Ashulia Model Town. Students from Daffodil International University are living there. There are six floors in the building, and each floor contains four flats except the sixth floor. There are two flats on the sixth floor. However, each flat has four rooms; three are double rooms and one is a single room. We have taken a flat as a reference to calculate the electric load. Electrical appliances of the rooms are listed in “Table 3.1.”

Table 3.1 Electrical Appliances in a Flat

SL	Name of Appliance	Rating (Watt)	Number of Appliances
01	Light	20	4
02	Ceiling Fan	75	2
03	Table Fan	60	3
04	Mobile Charger	18	2
		22	2
		30	3
05	Laptop	45	2
		65	2

We have partitioned the annual calendar into two distinct seasons, namely summer and winter. The summer season encompasses the period from March to October, while the winter season spans from November to February. The assessment of energy consumption for both summer and winter is meticulously performed, taking into account the distinctions between weekdays and weekends. Detailed elucidations of this evaluation can be found in the range of "table 3.2" through "table 3.5."

Table 3.2 Summer Energy Consumption for Weekdays (March to October)

Time	Light	Ceiling Fan	Table Fan	Laptop	Mobile Charger	Total Load	Overall Load
	Connected Load					For One Flat	Total Load×22
	Watt					$kW = \frac{Watt}{1000}$	kW
12 am to 01 am	40	150	120	110	0	0.420	9.240
01 am to 02 am	40	150	120	110	22	0.442	9.724
02 am to 03 am	40	150	120	110	0	0.420	9.240
03 am to 04 am	0	150	120	0	0	0.270	5.940
04 am to 05 am	0	150	120	0	0	0.270	5.940
05 am to 06 am	0	150	120	0	0	0.270	5.940
06 am to 07 am	0	150	120	0	0	0.270	5.940
07 am to 08 am	0	150	120	0	0	0.270	5.940
08 am to 09 am	40	75	60	155	40	0.370	8.140
09 am to 10 am	40	75	60	155	40	0.370	8.140
10 am to 11 am	20	75	0	0	0	0.095	2.090
11 am to 12 pm	20	75	0	0	0	0.095	2.090
12 pm to 01 pm	20	75	60	0	0	0.155	3.410

01 pm to 02 pm	20	75	60	0	0	0.155	3.410
02 pm to 03 pm	40	75	60	90	52	0.317	6.974
03 pm to 04 pm	40	75	60	90	52	0.317	6.974
04 pm to 05 pm	80	150	120	175	48	0.573	12.606
05 pm to 06 pm	80	150	120	175	48	0.573	12.606
06 pm to 07 pm	40	75	60	175	22	0.372	8.184
07 pm to 08 pm	40	75	60	220	30	0.425	9.350
08 pm to 09 pm	0	0	0	220	0	0.220	4.840
09 pm to 10 pm	40	75	60	175	18	0.368	8.096
10 pm to 11 pm	40	75	60	175	30	0.380	8.360
11 pm to 12 am	80	150	120	220	0	0.570	12.540

Table 3.3 Summer Energy Consumption for Weekends (March to October)

Time	Light	Ceiling Fan	Table Fan	Laptop	Mobile Charger	Total Load	Overall Load
	Connected Load					For one flat	Total Load×22
	Watt					$kW = \frac{Watt}{1000}$	kW
12 am to 01 am	40	150	120	110	0	0.445	8.9
01 am to 02 am	40	150	120	110	22	0.445	8.9
02 am to 03 am	40	150	120	110	0	0.445	8.9
03 am to 04 am	0	150	120	0	0	0.270	5.4
04 am to 05 am	0	150	120	0	0	0.270	5.4
05 am to 06 am	0	150	120	0	0	0.270	5.4
06 am to 07 am	0	150	120	0	0	0.270	5.4
07 am to 08 am	0	150	120	0	0	0.270	5.4
08 am to 09 am	40	150	120	155	40	0.460	9.2
09 am to 10 am	40	150	120	155	40	0.460	9.2
10 am to 11 am	0	150	120	0	0	0.270	5.4
11 am to 12 pm	0	150	120	0	0	0.270	5.4
12 pm to 01 pm	0	150	120	0	0	0.270	5.4
01 pm to 02 pm	0	75	0	0	0	0.165	3.3
02 pm to 03 pm	40	150	120	90	52	0.430	8.6
03 pm to 04 pm	40	150	120	90	52	0.430	8.6
04 pm to 05 pm	80	75	0	175	48	0.365	7.3
05 pm to 06 pm	80	75	0	175	48	0.365	7.3
06 pm to 07 pm	40	75	60	175	22	0.175	3.5
07 pm to 08 pm	40	75	60	220	30	0.175	3.5
08 pm to 09 pm	0	0	0	220	0	0	0

09 pm to 10 pm	40	75	60	175	18	0.205	4.1
10 pm to 11 pm	40	75	60	175	30	0.385	7.7
11 pm to 12 am	80	150	120	220	0	0.530	10.6

Table 3.4 Winter Energy Consumption for Weekdays (November to February)

Time	Light	Ceiling Fan	Table Fan	Laptop	Mobile Charger	Total Load	Overall Load
	Connected Load					For one flat	Total Load×22
	Watt					$kW = \frac{Watt}{1000}$	kW
12 am to 01 am	40	0	0	110	0	0.150	3.300
01 am to 02 am	40	0	0	110	22	0.172	3.784
02 am to 03 am	40	0	0	110	0	0.150	3.300
03 am to 04 am	0	0	0	0	0	0	0
04 am to 05 am	0	0	0	0	0	0	0
05 am to 06 am	0	0	0	0	0	0	0
06 am to 07 am	0	0	0	0	0	0	0
07 am to 08 am	0	0	0	0	0	0	0
08 am to 09 am	40	0	0	155	40	0.235	5.170
09 am to 10 am	40	0	0	155	40	0.235	5.170
10 am to 11 am	20	0	0	0	0	0.020	0.440
11 am to 12 pm	20	0	0	0	0	0.020	0.440
12 pm to 01 pm	20	0	0	0	0	0.020	0.440
01 pm to 02 pm	20	0	0	0	0	0.020	0.440
02 pm to 03 pm	40	75	60	90	52	0.317	6.974
03 pm to 04 pm	40	75	60	90	52	0.317	6.974
04 pm to 05 pm	80	0	0	175	48	0.303	6.666
05 pm to 06 pm	80	0	0	175	48	0.303	6.666
06 pm to 07 pm	40	0	0	175	22	0.237	5.214
07 pm to 08 pm	40	0	0	220	30	0.290	6.380
08 pm to 09 pm	0	0	0	220	0	0.220	4.840
09 pm to 10 pm	40	0	0	175	18	0.233	5.126
10 pm to 11 pm	40	0	0	175	30	0.245	5.390
11 pm to 12 am	80	0	0	220	0	0.300	6.600

Table 3.5 Winter Energy Consumption for Weekends (November to February)

Time	Light	Ceiling Fan	Table Fan	Laptop	Mobile Charger	Total Load	Overall Load
	Connected Load					For one flat	Total Load×22
	Watt					$kW = \frac{Watt}{1000}$	kW
12 am to 01 am	40	0	0	110	0	0.150	3.300
01 am to 02 am	40	0	0	110	22	0.172	3.784
02 am to 03 am	40	0	0	110	0	0.150	3.300
03 am to 04 am	0	0	0	0	0	0	0
04 am to 05 am	0	0	0	0	0	0	0
05 am to 06 am	0	0	0	0	0	0	0
06 am to 07 am	0	0	0	0	0	0	0
07 am to 08 am	0	0	0	0	0	0	0
08 am to 09 am	40	0	0	155	40	0.195	4.29
09 am to 10 am	40	0	0	155	40	0.195	4.29
10 am to 11 am	0	0	0	0	0	0	0
11 am to 12 pm	0	0	0	0	0	0	0
12 pm to 01 pm	0	0	0	0	0	0	0
01 pm to 02 pm	0	0	0	0	0	0	0
02 pm to 03 pm	40	150	120	90	52	0.452	9.944
03 pm to 04 pm	40	150	120	90	52	0.452	9.944
04 pm to 05 pm	80	0	0	175	48	0.303	6.666
05 pm to 06 pm	80	0	0	175	48	0.303	6.666
06 pm to 07 pm	40	0	0	175	22	0.237	5.214
07 pm to 08 pm	40	0	0	220	30	0.290	6.380
08 pm to 09 pm	0	0	0	220	0	0.220	4.840
09 pm to 10 pm	40	0	0	175	18	0.233	5.126
10 pm to 11 pm	40	0	0	175	30	0.245	5.390
11 pm to 12 am	80	0	0	220	0	0.300	6.600

3.2 System Design and Components

We have carefully integrated two abundant and sustainable natural resources into our well-thought-out system: sunlight and biomass. The solar panels efficiently capture solar radiation and convert it into clean electricity using photovoltaic processes. Our capacity to capture solar energy reduces our dependency on non-renewable resources. We have also completely understood the potential of biomass as a sustainable energy source. Biomass technology can effectively transform organic resources such as agricultural waste into energy that may be used. An environmentally friendly approach lessens the detrimental impacts of energy use on the environment while simultaneously ensuring a steady and reliable supply of power.

3.2.1 Solar Radiation

The system need have solar radiation in order to produce power. We can get the clearness index and sun radiation using location-specific data from the software, such as latitude, longitude, and time zone. In our example, the latitude, longitude, and time zone were 23°52.2' N, 90°19.1' E, and UTC+6 respectively. The baseline data for the solar resource is shown in the following table on a month-by-month basis. The baseline solar data is shown in "table 3.6."

Table 3.6 Solar Radiation Data

Month	Clearness Index	Daily Radiation
		(kWh/m^2/day)
January	0.632	4.360
February	0.616	4.920
March	0.599	5.590
April	0.552	5.760
May	0.481	5.300
June	0.405	4.530
July	0.382	4.230
August	0.404	4.290
September	0.415	4.020
October	0.517	4.320
November	0.601	4.280
December	0.644	4.210
Average	0.521	4.65

However, scaled average clearness index and daily radiation was 0.521 and 4.65 kWh/m^2/day, respectively. In "fig. 3.2" the global horizontal radiation on a daily basis can be illustrated.

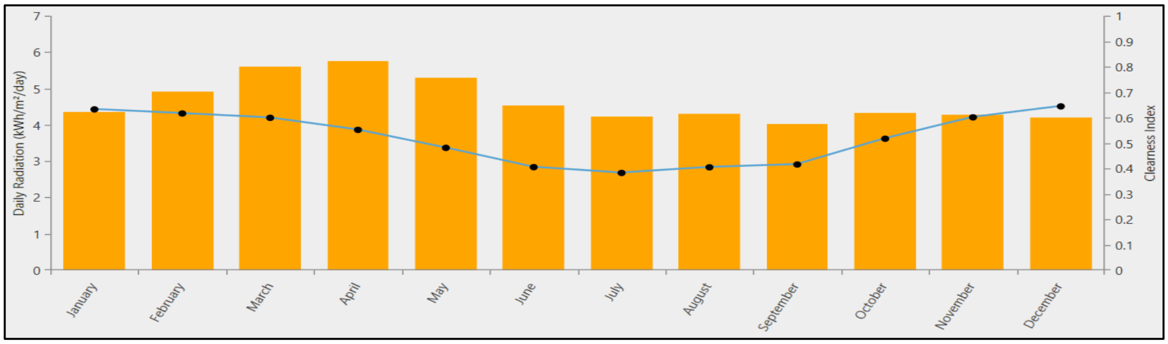


Fig. 3.2 Daily Radiation with Clearness Index

3.2.2 Biomass

We have considered cow dung as the biomass source. Since the case studied area has several cow farms, it will be very convenient to collect cow dung for generating electricity. According to our survey, we could collect 0.5 tons of cow dung every day, as shown in "table 3.7" and "fig. 3.3," respectively.

Table 3.7 Available Biomass (Cow dung)

Month	Available Cow Dung (kg/day)
January	500
February	500
March	500
April	500
May	500
June	500
July	500
August	500
September	500
October	500
November	500

December	500
Annual Average	500

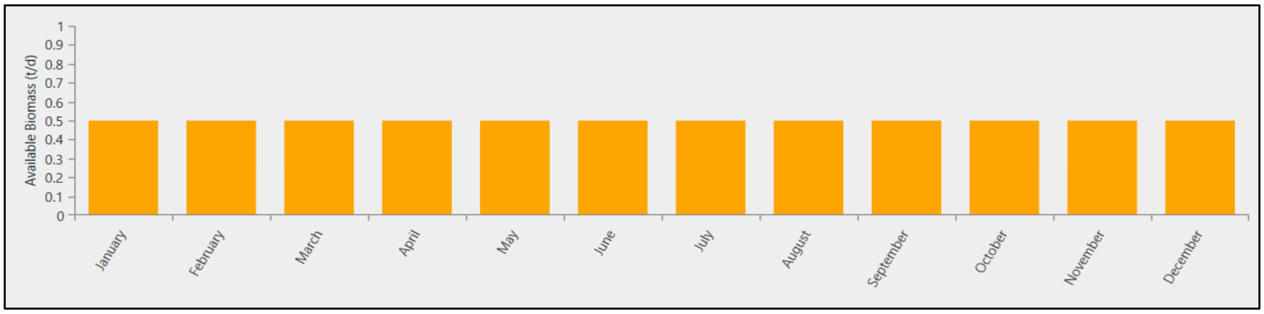


Fig. 3.3 Available Biomass

3.2.3 Load Profile

The yearly calendar has been divided into the summer and the winter seasons. The summer season is defined as March through October, and the winter season is defined as November through February. The evaluation of summer and winter energy use is done with great care, considering the differences between workdays and weekends. Detailed elucidations of this evaluation can be found in the range of "table " through "table."

Through meticulous integration of the energy consumption data extracted from the HOMER Pro software, we have derived the following key findings: The average daily energy consumption stands at 128.19 kWh, while the peak load registers at 21.91 kW. To visually represent the monthly load variations, we present "fig. 3.4," which showcases the month-wise load profile. Additionally, for a comprehensive understanding of the seasonal energy utilization trends, "fig. 3.5" depicts the seasonal profile. These graphical representations provide valuable insights into the patterns and trends that govern the energy consumption throughout the designated period.

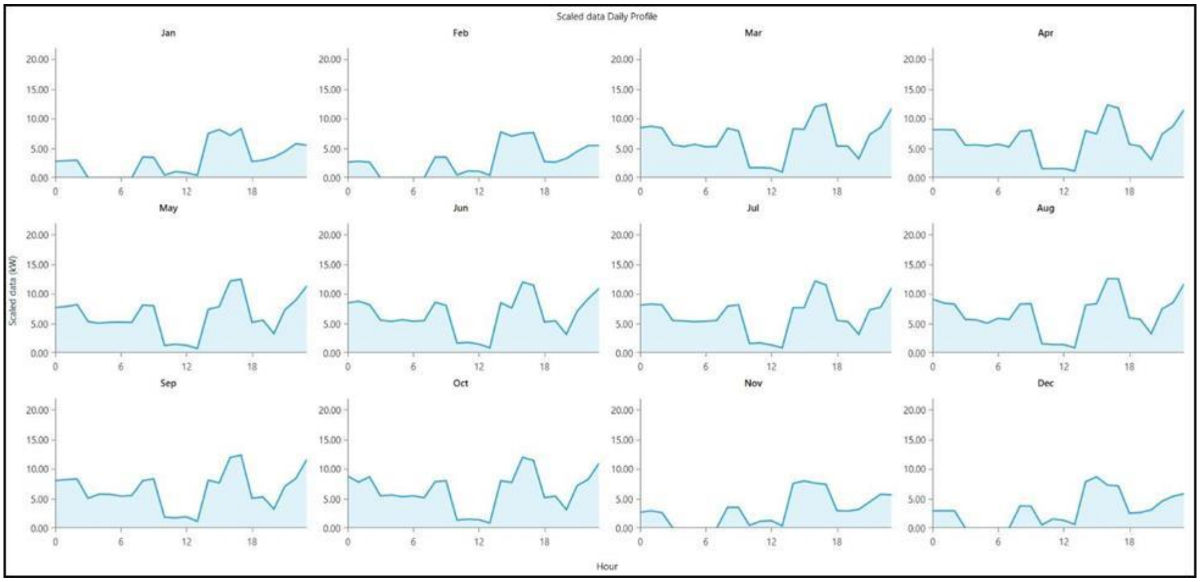


Fig. 3.4 Daily Load Profile

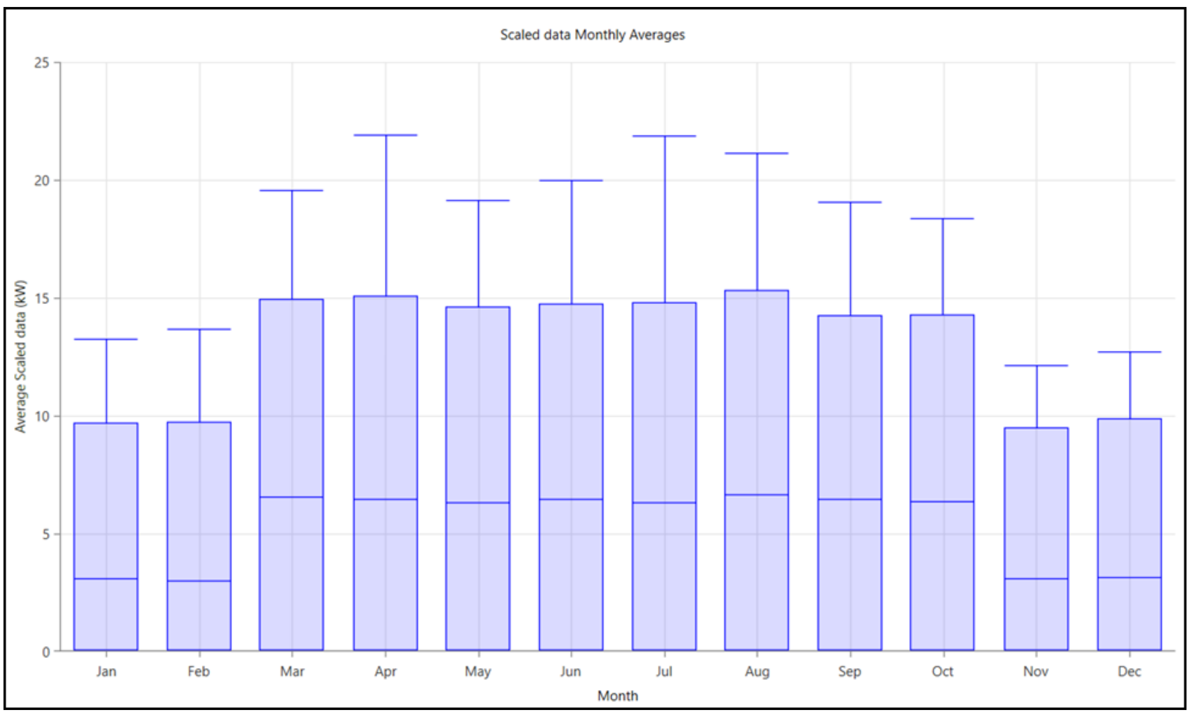


Fig. 3.5 Seasonal Profile

3.3 Design Specifications

Solar photovoltaic (PV) panels for capturing solar energy, a biogas generator for converting organic waste into electricity, an inverter for converting direct current (DC) power into alternating current (AC) suitable for the grid, a battery for energy storage to ensure a continuous power supply, and primary loads that use the generated electricity are some of the essential components of a grid-connected renewable energy system. In addition to maximizing the use of renewable energy sources like sunshine and organic waste, this integrated system offers energy security and flexibility, enabling the production and storage of power while enhancing the sustainability and dependability of the electrical grid, shown in “fig. 3.6.”

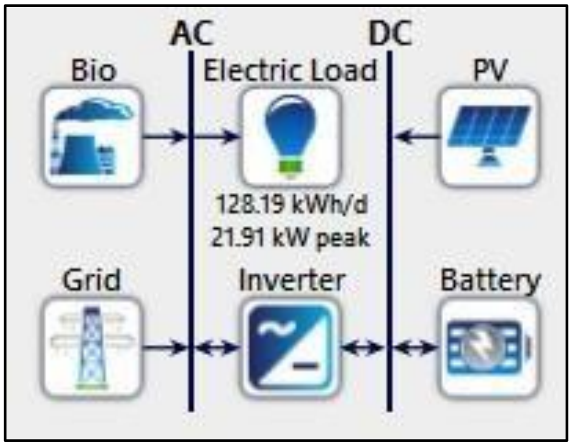


Fig. 3.6 Overall System Architecture

3.4 System Analysis

Our all-inclusive solution combines several parts to maximize energy efficiency. It is made up of solar panels to collect renewable energy, an inverter to change DC electricity into AC power, biomass technology to produce energy sustainably, and a battery to store extra energy for later use. For basic energy needs, we combine main load components and create grid connectivity for uninterrupted power delivery. By decreasing our dependency on traditional energy sources, this integrated system offers an eco-friendly and efficient approach to meeting our energy needs. Techno-Economic data of the components can be illustrated in “table 3.8” to “table 3.11.” Grid illustration can be seen in “table 3.12.”

Table 3.8 Techno-Economic Parameters of PV Array [21]

Photovoltaic Module		
	Unit	Value
Module Type	-	Flat Plate
Rated Output Power	kW	330

Capital Cost	BDT/kW	86,032
Replacement Cost	BDT/kW	86,032
O & M Cost	BDT/panel/year	1,075
Lifetime	Years	25
Derating Factor	%	85
Tracking System	-	No

Table 3.9 Techno-Economic Parameters of Inverter [21]

Inverter		
	Unit	Value
Type	-	On-grid Pure Sine
Capital Cost	BDT/kW	30,111
Replacement Cost	BDT/kW	30,111
O & M Cost	BDT/kW	430
Lifetime	Years	18
Efficiency	%	90
Rectifier Capacity	%	95
Rectifier Efficiency	%	85

Table 3.10 Techno-Economic Parameters of Battery [22]

Battery		
	Unit	Value
Type	-	Lead Acid
Capital Cost	BDT	27,208
Replacement Cost	BDT	27,208
O & M Cost	BDT/Year	1,075
Nominal Voltage	Volt	12
Nominal Capacity	kWh	1.7
Round-trip Efficiency	%	85
Maximum Charge Current	A	21.8
Maximum Discharge Current	A	230

Table 3.11 Techno-Economic Parameters of Biogas Generator [23]

Biogas Generator		
	Unit	Value
Capital cost	BDT/kW	32,262
Fuel Cost	BDT/ton	5000
Minimum Load Ratio	%	25
Lower Heating Value	MJ/Kg	5.5
Density	kg/m^3	0.720
Contents of Carbon	%	5
Contents of Sulfur	%	0
Lifetime	Hours	20,000

Table 3.12 Tariff Rate of Bangladesh Power Development Board [24]

Consumer Type	Unit Range	Energy Rate	Demand Rate
		(BDT/kWh)	(BDT/kW/month)
Life Line	0-50	4.35	35.00
First Class	0-75	4.85	
Second Class	76-200	6.63	
Third Class	201-300	6.95	
Fourth Class	301-400	7.34	
Fifth Class	401-600	11.51	
Sixth Class	600-above	13.26	

Our system is on sixth and we have considered the sell back price same as the energy rate.

3.5 Summary

In our study, we've divided the year into two seasons, summer and winter, carefully considering energy consumption variations between weekdays and weekends. Solar radiation is a crucial factor, and we used location-specific data (latitude, longitude, and time zone: 23°52.2' N, 90°19.1' E, UTC+6) to obtain a clearness index and solar radiation.

Cow dung, readily available from nearby cow farms, was chosen as our biomass source, with an estimated daily collection of 0.5 tons. Analyzing data from HOMER Pro software, we found that daily energy consumption averaged 128.19 kWh, with a peak load of 21.91 kW, and we illustrated monthly load variations.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Results

We then considered each of the four findings independently. In order to create a table, we took into account capital cost, net-present cost, renewable portion, cost of energy, and greenhouse gas (GHG) reduction. The optimized results can be seen in "fig. 4.1."

Architecture						Cost				System	
PV (kW)	Bio (kW)	Battery	Grid (kW)	Inverter (kW)	Dispatch	NPC (৳)	COE (৳)	Operating cost (৳/yr)	Initial capital (৳)	Ren Frac (%)	Total Fuel (tons/yr)
50.0	5.00		999,999	20.0	CC	৳4.09M	৳2.97	-৳75,237	৳5.07M	91.8	131
50.0	5.00	4	999,999	20.0	CC	৳4.28M	৳3.11	-৳69,161	৳5.18M	91.8	131
50.0			999,999	20.0	CC	৳4.71M	৳4.33	-৳15,262	৳4.90M	64.3	0
50.0		4	999,999	20.0	CC	৳4.89M	৳4.50	-৳9,185	৳5.01M	64.3	0
	5.00		999,999		CC	৳7.41M	৳9.73	৳560,460	৳163,100	74.4	131
			999,999		CC	৳8.02M	৳13.26	৳620,435	৳0.00	0	0
	5.00	4	999,999	10.0	CC	৳8.07M	৳10.60	৳580,052	৳573,042	74.4	131
		4	999,999	10.0	CC	৳8.68M	৳14.36	৳640,027	৳409,942	0	0

Fig. 4.1 HOMER Pro Optimization Result

We have considered following four cases:

SL	Case No	Combination
01	1	PV, Inverter, Biomass and Grid
02	2	PV, Inverter and Grid
03	3	PV, Inverter, Battery and Grid
04	4	Biomass and Grid

4.2 Discussions

In the following "Discussion" chapter, we embark on a comprehensive analysis and evaluation of the various systems examined in this study. This chapter serves as the platform to explore the findings, implications, and insights derived from our investigation into grid-connected energy systems, encompassing a wide spectrum of technologies and configurations. Through this discussion, we aim to provide a holistic understanding of the performance, potential, and limitations of each system, shedding light on their role in the broader context of sustainable energy generation and environmental impact.

4.2.1 Grid Connected Hybrid System with PV and Biomass

In this scenario, we integrated photovoltaic (PV) solar panels, an inverter system, biomass energy, and the conventional electrical grid. The PV panels and biomass energy provided renewable sources, while the inverter enabled efficient energy conversion. The grid acted as a supplementary source and a backup during times of low renewable energy availability.

The simulation indicates that in this situation 50 kW of PV panel capacity, 20 kW of on-grid inverter and 5 kW of biogas generator are needed. The output of the system is shown in "Table 4.1" with its performance.

Table 4.1: Evaluation of Grid Connected Hybrid System with PV and Biomass

SL	Overall Size		Unit	Value
01	PV Module		kWp	50
02	Inverter		kW	20
03	Biogas		kW	5
04	Initial Capital		Million BDT	5.07
05	Net Present Cost (NPC)		BDT	4.09
06	Cost of Energy (COE)		BDT/kWh	2.97
07	Renewable Fraction (REF)		%	91.8
08	Electricity Generation		kWh/year	117,813
09	Emission Reduction	CO_2	Tons	74.46
		SO_2		322.81
		NO		157.87

4.2.2 : Performance of Grid Connected PV System

In this case, we examined the performance of a system combining PV solar panels, an inverter, and the electrical grid. The simulation indicates that in this situation 50 kW of PV panel capacity and 20 kW of on-grid inverter are needed. The output of the system is shown in "Table 4.2" with its performance.

Table 4.2 Evaluation of Grid Connected PV System

SL	Overall Size	Unit	Value
01	PV Module	kWp	50
02	Inverter	kW	20
03	Initial Capital	Million BDT	4.90
04	Net Present Cost (NPC)	BDT	4.71

05	Cost of Energy (COE)		BDT/kWh	4.33
06	Renewable Fraction (REF)		%	64.3
07	Electricity Generation		kWh/year	43,951
08	Emission Reduction	CO_2	Tons	27.78
		SO_2		120.43
		NO		58.89

This configuration aimed to evaluate the effectiveness of relying solely on solar energy and the grid for energy needs. Once again, we used the data from the mentioned tables to optimize the system and analyze the results separately.

4.2.3 Grid Connected Hybrid System with PV and Energy Storage

Here, we focused on a setup that integrated PV solar panels, a battery storage system, and the electrical grid. The inclusion of battery storage allowed us to explore the feasibility of storing excess solar energy for later use, reducing dependence on the grid during peak hours or low solar availability. The simulation indicates that in this situation 50 kW of PV panel capacity, 20 kW of on-grid inverter and 48 V battery are needed. The output of the system is shown in "Table 4.3" with its performance.

Table 4.3 Evaluation of Grid Connected Hybrid System with PV and Energy Storage

SL	Overall Size		Unit	Value
01	PV Module		kWp	50
02	Inverter		kW	20
03	Battery		V	48
04	Initial Capital		Million BDT	5.01
05	Net Present Cost (NPC)		BDT	4.89
06	Cost of Energy (COE)		BDT/kWh	4.50
07	Renewable Fraction (REF)		%	64.3
08	Electricity Generation		kWh/year	43,951
09	Emission Reduction	CO_2	Tons	27.78
		SO_2		120.43
		NO		58.89

4.2.4 Grid Connected Biomass System

In this last scenario, our investigation centered on the combination of biomass energy and the electrical grid. Biomass, being a renewable energy source derived from organic materials, has its unique advantages. We utilized the data from the tables to assess the optimized performance of this particular setup. The simulation indicates that in this situation 5kW biogas generator is needed. The output of the system is shown in "Table 4.4" with its performance.

Table 4.4 Evaluation of Grid Connected Biomass System

SL	Overall Size		Unit	Value
01	Biomass		kW	5
02	Initial Capital		BDT	1,63,100
03	Net Present Cost (NPC)		BDT	7.41
04	Cost of Energy (COE)		BDT/kWh	9.73
05	Renewable Fraction (REF)		%	74.4
06	Electricity Generation		kWh/year	28,715
07	Emission Reduction	CO_2	Tons	18.15
		SO_2		78.68
		NO		38.48

CHAPTER 5
PROJECT MANAGEMENT

5.1 Task, Schedule, and Milestones

There are a few important activities involved in developing and implementing a grid-connected renewable energy system, along with a plan for managing these tasks and milestones for monitoring advancement. Below is a broad summary of these elements:

5.1.1 Levelized Cost of Energy

The Levelized Cost of Power (LCOE) is a measurement used to evaluate the typical expense of creating power from a specific power plant or energy framework over its lifetime. It addresses the expense per unit of power produced and is communicated as cash per kilowatt-hour (kWh). LCOE considers every one of the expenses related to the turn of events, development, activity, support, and decommissioning of the power plant, as well as the fuel costs, if any. It additionally considers the limit element of the plant, which is the proportion of the real energy result to its most extreme likely result. The limit factor represents the irregularity and fluctuation of specific energy sources, for example, solar and wind, as well as personal time for support and fixes.

The typical expense of delivering one unit of energy throughout the undertaking is addressed by the levelized cost of power. It incorporates all expenses, including startup costs, continuous expenses, support costs, fuel costs, and whatever other costs might be appropriate. The COE is figured by dividing the general undertaking cost by the aggregate sum of power produced over the span of the venture. Each kilowatt-hour (kWh) or some similar unit is utilized to communicate it. The COE helps with assessing how seriously estimated different energy creation innovations or activities are. It empowers policymakers, financial backers, and energy organizers to make informed choices in regards to the most monetarily practical and economical energy choices. Lower LCOE values show a more financially savvy power age, while higher qualities recommend greater expenses per unit of power delivered.

5.1.2 Electricity Generation Capacity

A grid-connected system's electricity generating capacity measures the highest amount of power that a network of power plants can generate together and input into the electrical grid. It is essential to preserve a steady, safe, and effective supply of energy for residences, companies, and industries in a certain area.

The entire maximum electrical power that may be produced by a network of power generating facilities that are connected to and integrated into the electrical grid is referred to as the electricity generation capacity of a grid-connected system. This capacity, which is commonly expressed in kWh, is the total production potential of all the grid-connected power plants and energy sources inside a certain geographic area, such as a nation, region, or even a continent.

A grid-connected system's ability to generate energy is a crucial part of an effective and dependable power supply infrastructure. It is essential for planning for future energy demands, guaranteeing grid stability, and satisfying the demand for power from companies and consumers. This capability includes a wide range of energy producing sources, such as geothermal, wind, solar, biomass, coal, natural gas, nuclear, and hydroelectric power. The total generating capacity comes from all these sources, and the proportions might differ greatly between grids.

The total potential of any power plant and generator in a grid-connected system determines its capacity, which is typically more than the actual demand for energy. This spare capacity is necessary to offset unanticipated swings, meet periods of high electricity demand, and handle specialized power plant maintenance and outages.

To guarantee a steady supply of electricity, grid operators and utility companies keep a careful eye on and manage this capacity. In order to satisfy rising power demand and environmental goals, they analyze the generating mix, analyze the availability of various energy sources, and make plans for future capacity increases or retirements. The formulation of energy policies, infrastructure investments, pricing strategies, and the general energy security and resilience of an area's electrical grid all depend on an understanding of the capacity for producing power.

5.1.3 Renewable Energy Fraction (REF)

The percentage of total energy consumption or electricity output that comes from renewable energy sources is known as the renewable energy fraction. This indicator serves as a basic gauge of a country's or region's dedication to environmentally friendly and sustainable energy sources. It is computed by dividing the total energy produced or consumed during a given time period or geographic region by the energy derived from renewable sources, such as biomass, geothermal, solar, wind, hydropower, and tidal energy. The percentage of renewable energy is critical because it shows how far we've come in lowering our dependency on fossil fuels, which are not good for the environment and contribute to climate change mitigation, better air quality, and increased energy security. Its value can differ significantly between locations due to a variety of factors, including public support for renewable energy sources, government regulations and incentives, the availability of renewable resources, and technology improvements. Aiming to meet sustainability goals, switch to cleaner energy sources, and lower carbon emissions, many nations and regions set high goals for growing the share of renewable energy. The intermittent nature of some renewable energy sources, the limits of energy storage, and the requirement for a strong grid infrastructure make reaching a high renewable energy proportion difficult. The renewable energy percentage is critical to the worldwide effort to achieve a greener and more sustainable energy future as renewable technology costs come down and new breakthroughs in energy storage and grid integration are made.

5.1.4 GHG Reduction

To produce one kilowatt-hour electricity from any non-renewable energy source, several toxic greenhouse gases released to the environment, depicted in "Table 5.1."

Table 5.1 GHG Emissions Data [25]

Emissions	Quantity
	Kg/kWh
Carbon dioxide (CO_2)	0.632
Sulphur dioxide (SO_2)	2.74
Nitrogen oxide (NO)	1.34

5.2 Resources and Cost Management

In this section, a comprehensive and thorough analysis has been undertaken, encompassing all four considered cases, with a focus on critical factors such as initial capital cost, Net Present Cost (NPC), Cost of Electricity (COE), and Renewable Energy Fraction (REF). The primary aim of this investigation was to conduct a comparative assessment of these parameters across the different cases, with the ultimate objective of revealing their respective strengths and weaknesses.

The results of this analysis are substantiated through the use of informative graphical representations. Specifically, Figures 5.1 through 5.5 depict bar graphs showcasing various data comparisons, including Initial Capital, Cost of Energy, REF (%), GHG Reduction, and Electricity Generation, for different cases.

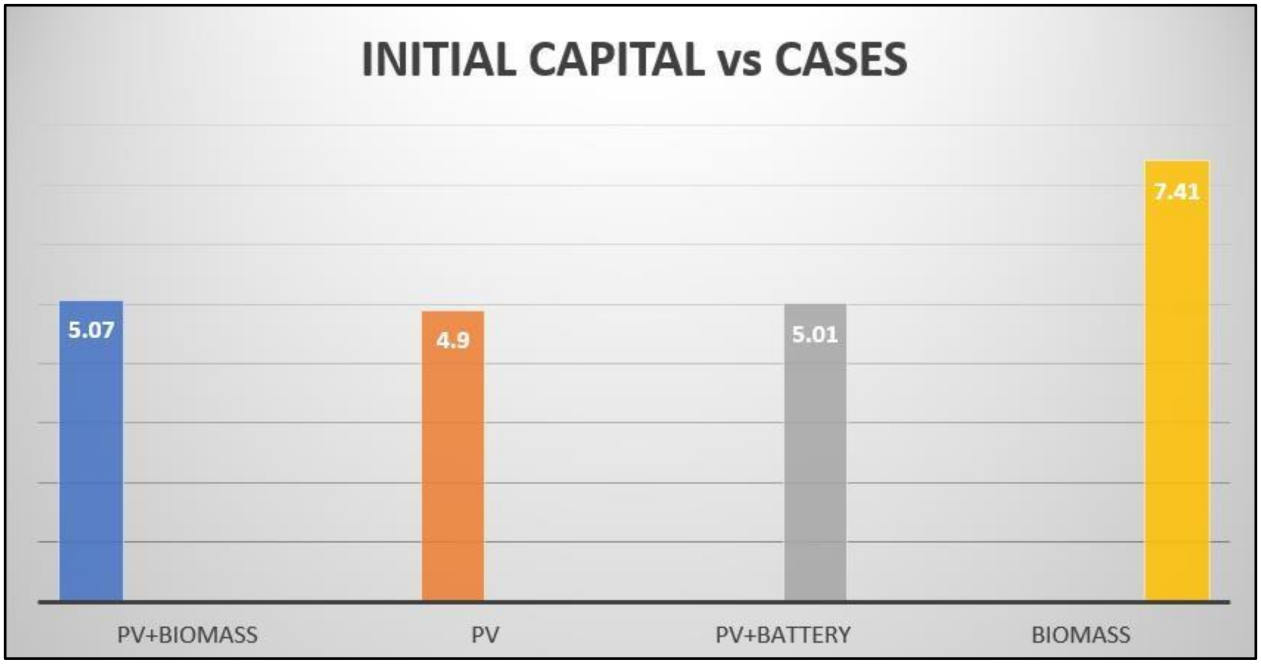


Fig. 5.1 Bar graph of Initial Capital (BDT) vs All the Cases

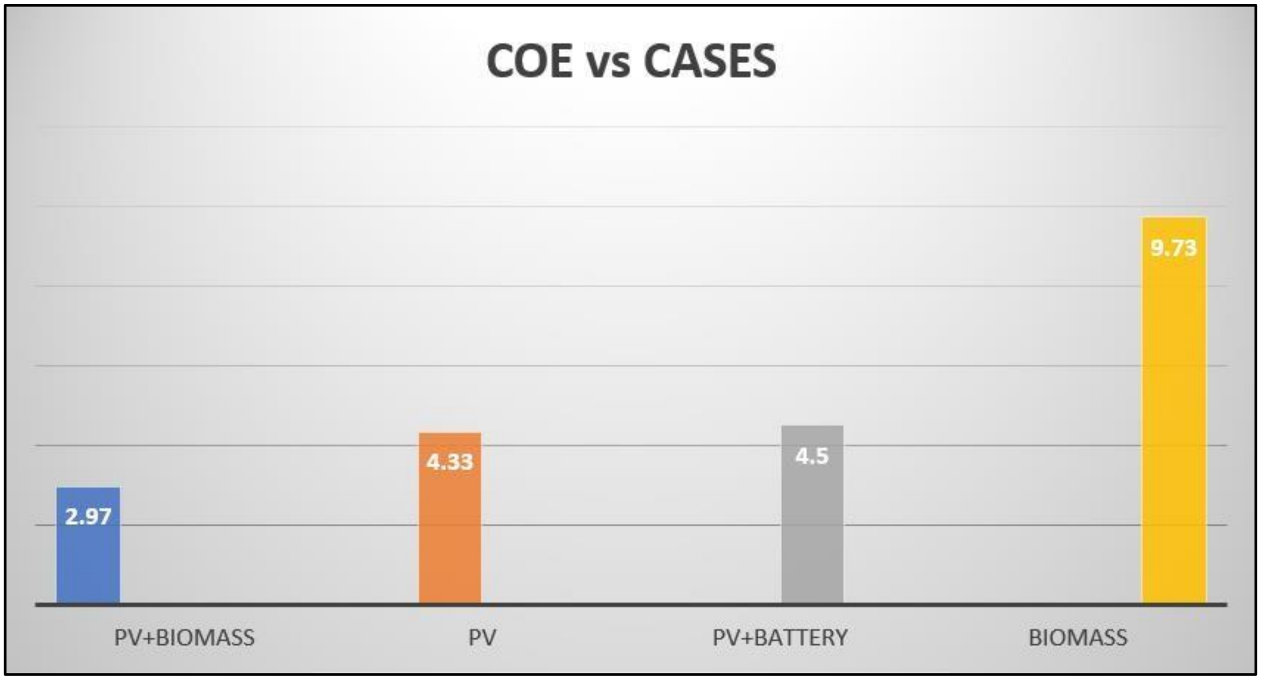


Fig. 5.2 Bar graph of Cost of Energy (BDT/kWh) vs All the Cases

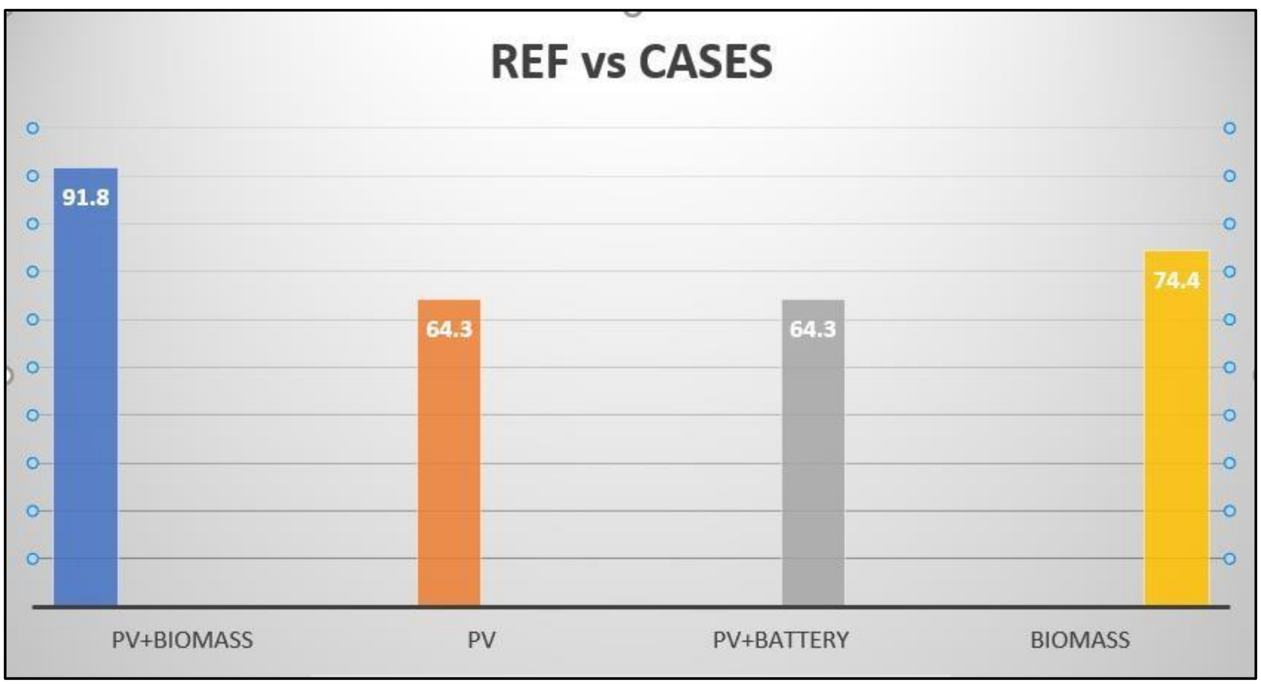


Fig. 5.3 Bar graph of REF (%) vs All the Cases

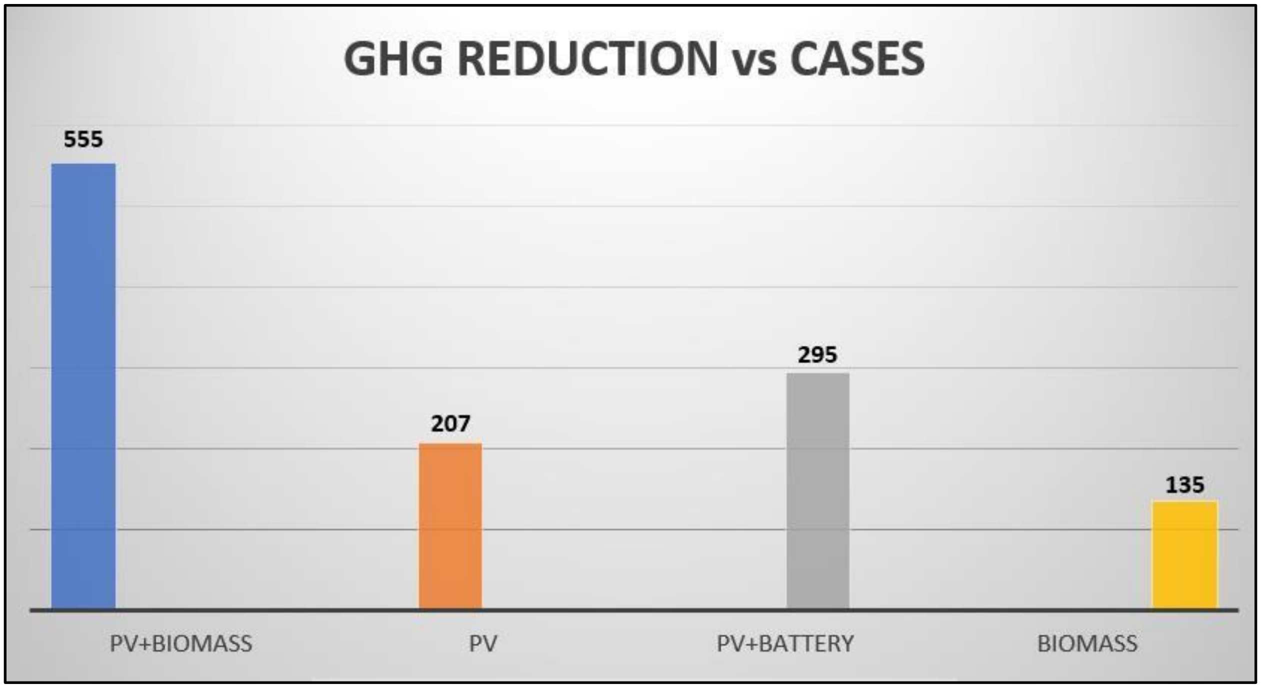


Fig. 5.4 Bar graph of GHG Reduction (Tons/year) vs All the Cases

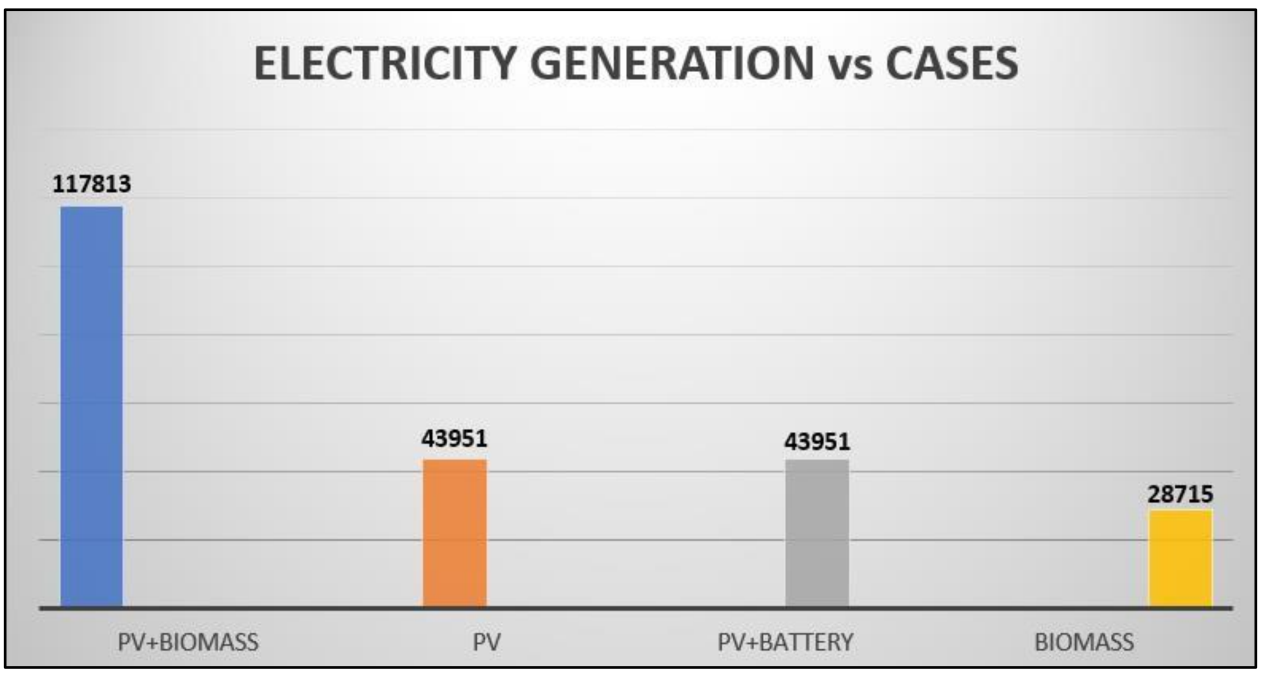


Fig. 5.5 Bar graph of Electricity Generation (kWh/year) vs All the Cases

5.3 Lesson Learned

Upon meticulous comparison of all cases, it is apparent that "Case 1" stands out as the most harmonious and viable option. "Case 1" entails an integrated system that comprises Photovoltaic (PV) technology, Inverter, Biogas generator, and Grid interconnection. The empirical evidence derived from this analysis firmly supports the proposition to adopt "Case 1" as the optimal solution in the subsequent chapter. The proposed system architecture can be illustrated in “fig. 5.6.”

The proposed system demonstrates commendable attributes, effectively striking a balance between initial capital investment, long-term NPC, COE, and the overall utilization of renewable energy sources. This is substantiated by the favorable REF values, indicating a significant reliance on renewable resources. Additionally, "Case 1" showcases a remarkable reduction in greenhouse gas emissions, thus contributing significantly to environmental sustainability and fostering a path towards a greener and more ecologically responsible energy landscape. This endeavor represents a stride towards a sustainable and prosperous future. The profound analytical insights and sound conclusions drawn from this study hold the potential to serve as invaluable information for policymakers, researchers, and practitioners, fostering the development of more effective and sustainable energy systems on a global scale.

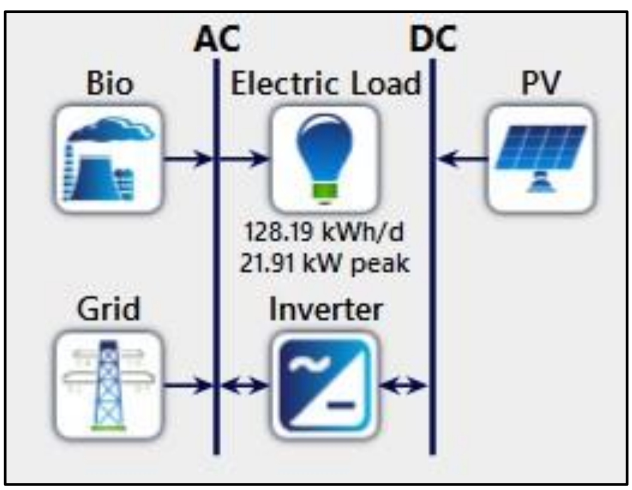


Fig. 5.6 Proposed System Architecture

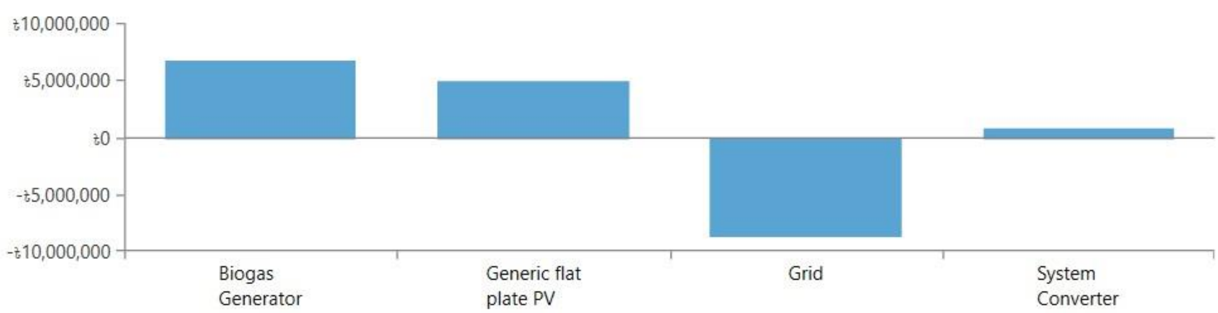
CHAPTER 6

IMPACT ASSESSMENT OF THE PROJECT

6.1 Economical, Societal and Global Impact

In this section, the cost breakdown of a microgrid system reveals a strategic emphasis on renewable energy. This not only makes financial sense but also has broader implications. The microgrid's significant annual power output reduces reliance on fossil fuels, mitigates greenhouse gas emissions, and enhances local quality of life.

"Fig. 6.1" illustrates the cost breakdown of the system, with the biogas generator ranked highest, the solar module as the second highest, and the inverter as the lowest. The grid is separated from the other components as it is not cost-dependent and serves as an external energy source or backup. This graphical representation offers valuable insights into the allocation of financial resources within the system, aiding decision-making for renewable energy investments.



Component	Capital (৳)	Replacement (৳)	O&M (৳)	Fuel (৳)	Salvage (৳)	Total (৳)
Biogas Generator	৳163,100.00	৳732,502.48	৳56,622.52	৳5,945,364.86	-৳1,678.10	৳6,895,911.76
Generic flat plate PV	৳4,301,600.00	৳0.00	৳694,854.01	৳0.00	৳0.00	৳4,996,454.01
Grid	৳0.00	৳0.00	-৳8,749,732.39	৳0.00	৳0.00	-৳8,749,732.39
System Converter	৳602,220.00	৳215,243.81	৳222,353.28	৳0.00	-৳88,162.88	৳951,654.21
System	৳5,066,920.00	৳947,746.29	-৳7,775,902.57	৳5,945,364.86	-৳89,840.98	৳4,094,287.60

Fig. 6.1 Cash Flow Summary (Component Type)

Moreover, "fig. 6.2" displays the nominal cash flows.

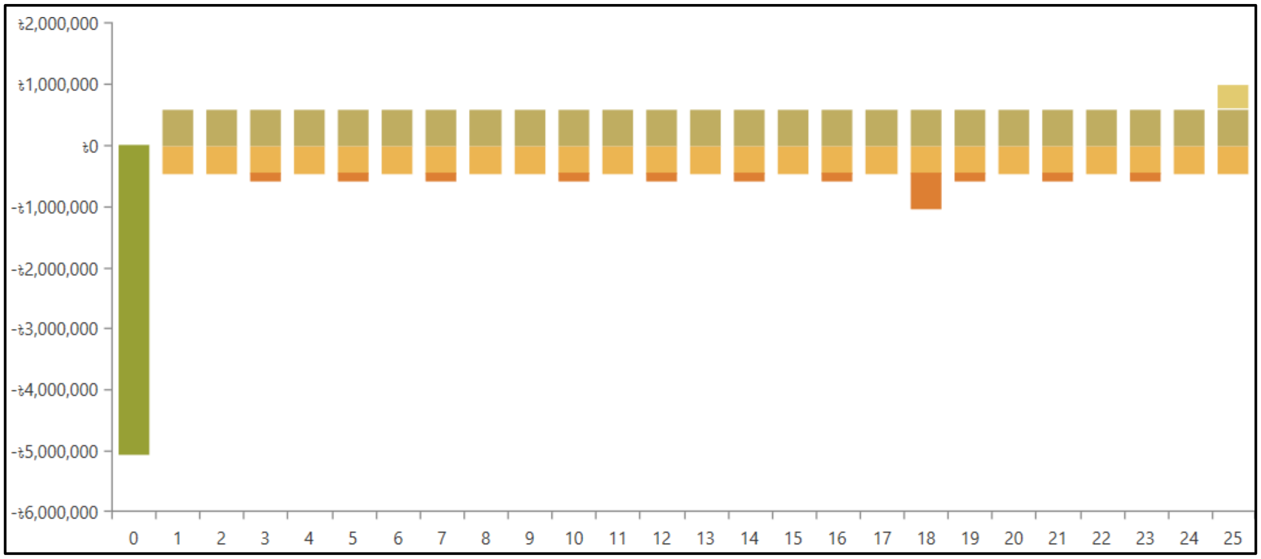


Fig. 6.2 Nominal Cash Flow of the System

The strategy portrayed in the illustration demands a substantial initial capital outlay, as meticulously illustrated in the accompanying graphical representation. It is noteworthy that a pivotal juncture in the system's evolution occurred in its 18th year, marked by the replacement of the inverter. This noteworthy event underscores the strategy's commitment to enduring sustainability, as it continues to adapt and thrive even beyond its initial phases.

Furthermore, the system's financial outlay for operational expenses demonstrates a commendable consistency throughout the entirety of its lifecycle. This unwavering stability in operating costs serves as a testament to the meticulous planning and astute management that underpin the strategy's execution. This cohesive financial framework not only enhances the system's overall cost-effectiveness but also fortifies its reputation for reliability, fostering an environment of trust and dependability.

The harmonious interaction with the conventional grid exemplifies an ethical coexistence that can serve as a global model for energy transition. Efficient resource management within the microgrid promotes sustainability and reduces waste, benefiting both local communities and the global environment. The surplus power contributed back to the grid transforms consumers into contributors to the broader energy landscape, promoting grid stability and resilience. In summary, this microgrid project showcases the potential for sustainable energy practices, offering social and global benefits through reduced environmental impact, energy security, and responsible energy consumption. The diagram labeled "Fig. 6.3" illustrates the monthly averages of electric production. Upon careful examination of the bar graph, it becomes evident that both photovoltaic

(PV) and biomass energy sources held a prominent sway throughout the entire year. Nevertheless, certain months witnessed a consistent reliance on grid electricity, punctuating the otherwise dominant self-sufficiency of the system.

Notably, PV-generated power consistently held the upper hand, achieving its zenith in March and reaching its nadir in February, June, July, and September. Concurrently, power harnessed from biomass sources exhibited a remarkable constancy over the temporal span under study.

Remarkably, the system displayed an appreciable degree of autonomy from the conventional grid, manifesting minimal power intake from it. This autonomy was particularly pronounced in the months of January, February, November, and December, during which power uptake from the grid registered as negligible. Consequently, the system stands poised to be classified as self-sufficient, as its robust energy production and judicious consumption choices underscore its potential to operate autonomously.

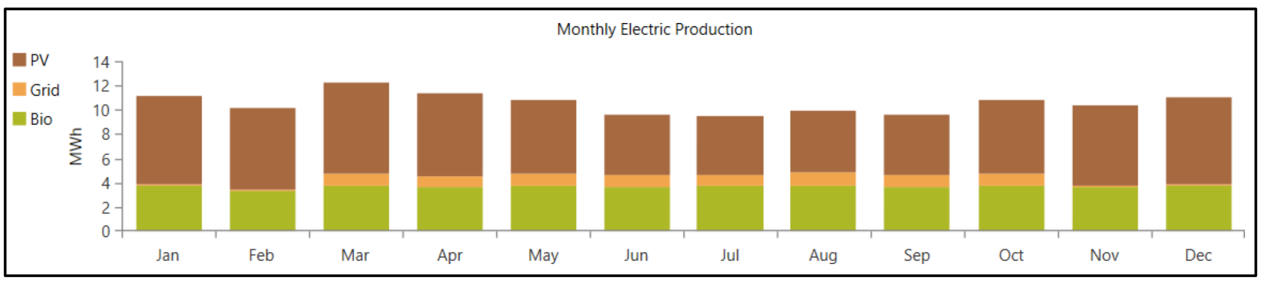


Fig. 6.3 Monthly Average Electric Production

The microgrid's electricity generation and consumption are shown in "table 6.1."

Table 6.1: Electricity Generation and Consumption of the Microgrid

		kWh/year	Percentage (%)
Production	PV	74,013	58.5
	Biogas	43,800	34.6
	Grid Purchase	8,740	6.91
	Total	126,553	100
Consumption	Load Consumption	46,790	43.9
	Grid Sales	59,783	56.1
	Total	106,573	100
	Excess Electricity	13,976	11

Our planned microgrid demonstrates its formidable capabilities by generating an impressive annual power output of 126,553 kWh. This commendable achievement constitutes a staggering

93.1% of the total electricity produced, solidifying the microgrid's pivotal role as a dominant and sustainable energy source.

Furthermore, our engagement with the conventional grid showcases a thoughtful balance, with a judicious purchase of 8,740 kWh, equivalent to 6.91% of our energy needs. This harmonious interaction highlights the microgrid's capacity to seamlessly integrate with external sources while preserving its autonomy and self-sufficiency.

Delving deeper into our energy dynamics, our discerning load management strategy optimized our energy utilization to 46,790 kWh. This astute allocation underscores our commitment to efficient resource management and sustainability, while simultaneously fostering a vibrant and robust energy ecosystem.

Intriguingly, the symbiotic relationship between our microgrid and the grid is further illuminated by the surplus power we contributed back, amounting to an impressive 59,783 kWh. This intricate exchange reflects our role not only as consumers but also as valuable contributors to the broader energy landscape.

Astoundingly, the aggregate of these interactions' manifests in an exceptional surplus of 13,976 kWh of electricity. This surplus stands as a testament to the efficacy of our microgrid strategy, solidifying its position not just as a prudent energy solution but as a transformative force poised to shape our energy future.

6.2 Environmental and Ethical Issues

The PV-Biomass hybrid system demonstrates noteworthy environmental and ethical benefits. By producing a cumulative amount of 111,813 kilowatt-hours (kWh) of energy, the majority of which (58.5%) is derived from photovoltaic (PV) solar systems and 34.6% from sustainable biomass sources, we have significantly diminished the reliance on power generated from traditional sources. The modest fraction (6.91%) that was obtained from the grid was effectively administered. It is worth mentioning that a total of 59,783 kilowatt-hours (kWh) of the energy we produced was successfully sold back to the electrical grid. This exemplifies the capacity of our system to fulfil our requirements and its potential to offer renewable energy to the broader community, thereby diminishing dependence on fossil fuels and mitigating the corresponding environmental consequences.. It also serves as a testament to our dedication to adopting responsible and sustainable energy strategies, thereby aligning with ethical principles.

6.3 Comparison with Existing System

6.3.1 COE Comparison

For the grid-only system and the system we developed, the levelized cost of electricity (COE) was ৳2.97 and ৳13.26, respectively. This formula may be used to determine the difference:

$$\%Difference\ of\ COE = \frac{Grid\ only\ System - Proposed\ System}{Grid\ only\ System} \times 100\% \quad (6.1)$$

The cost of producing power per unit may be cut by 77.6% thanks to the technique we've developed. Hence, one unit of energy may be produced from our planned system at a cost that is 77.6% less than the grid-only system.

6.3.2 NPC Comparison

In the world of power, two systems stood side by side, The grid-only way, costing ৳8.02M, a hefty price to guide. But our own creation, the developed scheme we'd wield, came at ৳4.09M, a smarter path revealed. Choices to make, between the old and the new, Different costs they bore, for us to pursue.

This formula may be used to determine the difference:

$$\%Difference\ in\ NPC = \frac{Grid\ only\ System - Proposed\ System}{Grid\ only\ System} \times 100\% \quad (6.2)$$

Our system's architecture enables a 49% reduction in NPC. Hence, a 49% increase in the system's net present value is possible.

6.4 Other Concern (Profit Calculation)

In the realm of energy economics and revenue analysis, a powerful tool emerges in the form of a straightforward yet pivotal formula. This formula unveils the intricate relationship between energy consumption, pricing, and the resultant annual revenue. It serves as a compass guiding us through the intricate labyrinth of energy markets and fiscal projections. With this formula at our disposal, the annual revenue from energy sales or consumption can be accurately ascertained, shedding light on the financial prospects of an energy-based venture.

Let us consider a practical application of this formula within the context of a microgrid system. This microgrid, an autonomous energy entity, stands as a beacon of sustainable energy generation. Annually producing a commendable 117,813 kilowatt-hours (kWh) of power, it radiates promise and potential. Leveraging the predictive power of the formula, we embark on estimating the inaugural year's financial horizon.

$$\text{Annual income} = (\text{Energy Sold} \times \text{Energy Price}) \qquad (6.3)$$

Harnessing the formula's prowess, we calculate the projected revenue:

$$\text{Annual income} = (117{,}813\ \text{kWh} \times 13.56) \qquad (6.4)$$

At this juncture, anticipation meets calculation as we place our trust in the energy pricing dynamics. And lo, with a calculated energy price, the formula unveils its magic, yielding a figure that resonates in the realm of financial reality:

First Year's Income ≈ 1.56 million BDT

In the realm of financial analysis and investment assessment, a series of illuminating formulas serve as guiding beacons, shedding light on the intricate path towards assessing the viability and profitability of a venture. These formulas, akin to keys unlocking the doors of financial insight, enable us to navigate the landscape of capital recovery, payback periods, total revenue, and lifetime profits. Each equation reveals a different facet of the financial journey, helping us decipher the potential gains that await.

The initial step in this financial voyage involves the calculation of the first year's capital recovery. This pivotal metric is unveiled through the elegant formula:

$$\%First\ year\ capital\ recovery = \frac{First\ year\ income}{Capital} \times 100\% \qquad (6.5)$$

Within this formula, the symbiosis of the first year's income and the capital invested harmoniously intertwines. Through meticulous calculation, a numerical representation emerges, painting the picture of capital recovery. As the numbers converge, the result crystallizes, indicating that a notable 30.81% of the initial capital can be recuperated within the span of a solitary year.

Expanding our vista, we embark on the quest to unveil the elusive payback period – the temporal horizon needed to reclaim the capital invested. This endeavor, simplified yet profound, is illuminated by the equation

$$Payback\ period = \frac{Capital}{Annual\ Income} \qquad (6.6)$$

With focused attention on the interplay between capital and annual income, this formula manifests as a bridge connecting financial outlay and incoming revenue. Delving into the realm of numbers, the calculation unfurls a revelation: the initial investment shall be restored in a period of approximately 3 years and 3 months, an undeniable testament to the project's promising financial dynamics.

The expedition continues, leading us to uncover the overarching panorama of total revenue – the accumulation of annual income over the projected lifespan. This panoramic perspective is encapsulated within the equation:

$$Total\ income = Annual\ Income \times Lifetime \qquad (6.7)$$

As the threads of annual income and projected lifetime intertwine, a sumptuous tapestry of potential financial gain is woven. Calculation transforms abstraction into tangibility, revealing a staggering total revenue of 39 million Bangladeshi Taka (BDT). A momentous realization follows, as this sum dwarfs the initial investment, standing resolutely at 7.69 times its value.

Culminating this financial odyssey, we turn our gaze towards the ultimate metric – the project's lifetime profit. With bated breath, we delve into the depths of the formula:

$$Lifetime\ profit = Total\ income - Capital \qquad (6.8)$$

This equation, symbolic of the entire venture's financial narrative, distills years of revenue generation and capital deployment into a single numeric revelation. Calculation leaves no room for ambiguity, disclosing a triumphant lifetime profit of 33.93 million BDT, a remarkable achievement that magnifies the initial investment by a factor of 6.69.

CHAPTER 7
CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

In the context of Bangladesh's energy landscape, it is evident that the utilization of renewable energy for power generation remains alarmingly low. The urgent need to shift towards more sustainable sources of energy is paramount for a nation that aspires for a cleaner, greener future. As we delve into the realm of grid-connected hybrid microgrid systems, our investigation reveals a glimmer of hope. We embarked on a journey of meticulous design, simulation, and optimization, culminating in the creation of a grid-connected renewable energy system that holds the promise of transforming Bangladesh's energy narrative.

Among the array of configurations explored, four grid-connected optimized systems emerged as beacons of potential: the PV and biomass hybrid, PV-only, PV with battery storage, and biomass-only. These configurations, each carefully calibrated, present a spectrum of possibilities that underscore the versatility of hybrid microgrid systems. With precision, we determined that the most optimized ensemble comprises a 50 kW photovoltaic (PV) setup, a 20 kW inverter, a 5 kW biogas generator, and a 60-volt battery. The economic feasibility of these systems is quantified through the Cost of Energy (COE), revealing values of 2.97 BDT, 4.33 BDT, 4.89 BDT, and 9.73 BDT for the respective configurations. These figures stand as a testament to the financial viability of embracing renewable energy solutions. Furthermore, the allure of sustainability is quantified by the Renewable Energy Fraction (REF), showcasing percentages of 91.8%, 64.3%, 64.3%, and 74.4% for the respective systems. The environmental impact of these systems is tangible, with annual greenhouse gas (GHG) reductions of 555 tons, 207 tons, 295 tons, and 135 tons, respectively.

Amidst this data tapestry, a clear choice emerged – the PV-Biomass hybrid system, selected based on the trifecta of the lowest COE, the highest REF, and the most significant GHG reduction. This system, requiring a capital investment of 5.07 million Bangladeshi Taka (BDT), demonstrated remarkable prowess. It generated a total of 111,813 kWh of energy, with 58.5% attributed to PV, 34.6% to biomass, and a mere 6.91% (8,740 kWh) procured from the grid. Impressively, 59,783 kWh were sold back to the grid, exemplifying the potential for two-way energy exchange.

Financially, the PV-Biomass hybrid system proved its mettle. The first-year capital recovery reached an encouraging 30.81%, while the payback period stood at a mere 3 years and 3 months. The system's revenue generation was a true marvel, amassing a total of 39 million BDT, a remarkable 7.69 times the initial capital investment.

Comparing our visionary hybrid microgrid system with the existing grid-only paradigm, the disparities are stark. The prospect of producing a unit of energy at a cost 77.6% lower than the conventional grid, coupled with a notable 49% surge in net present value, paints a compelling picture of transformation.

As we conclude this journey, it is clear that grid-connected hybrid microgrid systems, epitomized by the PV-Biomass hybrid, hold the potential to redefine Bangladesh's energy trajectory. The path to sustainability, economic feasibility, and environmental stewardship is illuminated by the data before us. With thoughtful implementation and a collective commitment to change, the nation can stride confidently towards a future powered by clean, resilient, and cost-effective energy solutions.

7.2 New Skills and Experiences Learned

In the course of our project, we've acquired valuable expertise and experiences in the realm of renewable energy. This includes the ability to design grid-connected renewable energy systems, incorporating elements like photovoltaic and biomass components into microgrid setups. We've also become proficient in utilizing software tools, such as HOMER Pro, to model and optimize complex energy systems, aiding in data-driven decision-making.

Additionally, we've developed skills in conducting cost-benefit analyses and economic feasibility studies, which are vital for assessing the financial viability of renewable energy projects. Furthermore, we've gained the capability to evaluate the positive environmental impact of renewable energy systems, especially in terms of reducing greenhouse gas emissions.

We've also deepened our understanding of the policies and regulations that pertain to renewable energy integration. Our data handling and analysis skills have improved significantly, enabling us to process information related to energy consumption, solar irradiance, and biogas production.

Lastly, we've obtained practical experience in efficiently managing research projects from initial concept to execution and reporting. Collaboration with experts from various fields has underscored the importance of developing a comprehensive understanding of projects.

7.3 Future Recommendations

7.3.1 Technological Advancement: Staying abreast of emerging renewable energy technologies is essential, particularly in Bangladesh. This includes advancements like more efficient solar panels, improved battery storage solutions, and enhanced biogas generation systems, all of which can elevate the performance and cost-effectiveness of renewable energy systems within the country.

7.3.2 Implementing Real-Time Data Monitoring and Analysis: A tailored system for continuous data monitoring and analysis, specifically designed for Bangladesh, can be immensely beneficial. This system should focus on tracking energy production, consumption, and environmental impact, providing valuable insights for optimizing renewable energy systems and monitoring their performance within the country.

7.3.3 Enhancing Grid Integration and Energy Trading: Exploring opportunities for closer integration with the primary power grid in Bangladesh and devising strategies for energy trading within the country is crucial. This can substantially enhance the economic viability of microgrid systems within the unique context of Bangladesh.

7.3.4 Policies and Regulations Advocacy: Collaborating with governmental and non-governmental organizations in Bangladesh to advocate for policies and regulations that foster the adoption of renewable energy within the country is of utmost importance.

7.3.5 Community Engagement: Encouraging community participation and awareness within Bangladesh is a priority. This can be achieved through the implementation of training programs, workshops, and educational initiatives, empowering local residents to reap the benefits of microgrid systems. This engagement is vital for the success of renewable energy projects in Bangladesh.

7.3.6 Investigating Scalability: Exploring the potential to scale up the proposed PV-Biomass hybrid microgrid system to cater to larger areas or communities within Bangladesh is a significant consideration. Expanding the project's scope can lead to a more substantial impact on energy sustainability within the country.

7.3.7 Developing Innovative Energy Storage Solutions: Research and innovation in the field of energy storage is essential, including advanced battery technologies and renewable hydrogen storage. This is particularly important in addressing energy intermittency challenges and ensuring a stable power supply within Bangladesh.

7.3.8 Assessing Long-Term Environmental Impact: Conducting a comprehensive study to evaluate the sustainability and long-term environmental impact of the PV-Biomass hybrid system is essential. This study should place a specific focus on reducing greenhouse gas emissions within Bangladesh.

7.3.9 Economic Risk Analysis: Developing advanced economic models and conducting in-depth risk assessments tailored to the unique circumstances of Bangladesh is crucial. This will provide a better understanding of the financial uncertainties associated with renewable energy projects within the country.

7.3.10 International Collaboration: Exploring opportunities for international collaboration and knowledge exchange with countries that have successfully implemented renewable energy solutions is beneficial. Learning from their experiences and best practices and applying them within Bangladesh can accelerate the growth of clean energy initiatives in the country.

REFERENCES

01. M. K. G. Deshmukh, M. Sameeroddin, D. Abdul and M. A. Sattar, "Renewable energy in the 21st century: A review," Materials Today: Proceedings, vol. 80, no. 3, pp. 1756-1759, 2023.

02. M. Farghali, A. I. Osman, I. M. A. Mohamed, Z. Chen, and L. Chen, "Strategies to save energy in the context of the energy crisis: a review," Environmental Chemistry Letters, p. 2003–2039, 2023.

03. UN, "Sustainable Development Goals: 17 Goals to Transform our World," United Nations (UN), 02 February 2023. [Online]. Available: https://www.un.org/en/exhibits/page/sdgs-17-goals-transform-world.

04. S. A. Sy and L. Mokaddem, "In developing nations, energy is a critical enabler for social equity and poverty alleviation.," Energy Research & Social Science, vol. 89, p. 102562, 2022.

05. H. Blum and L. F. Legey, "The challenging economics of energy security: Ensuring energy benefits in support to sustainable development," Energy Economics, vol. 34, no. 6, pp. 1982-1989, 2012.

06. IEA, "World Energy Outlook 2022," International Energy Agency (IEA), [Online]. Available: https://www.iea.org/reports/world-energy-outlook-2022/executive-summary.

07. USGS, "United States Assessments of Undiscovered Oil and Gas Resources," Central Energy Resources Science Center, [Online]. Available: https://www.usgs.gov/centers/central-energy-resources-science-center/science/united-states-assessments-undiscovered-oil.

08. IEA, "Global Energy Review," International Energy Agency, 2021.

09. SREDA, "National Database of Renewable Energy," [Online]. Available: http://www.renewableenergy.gov.bd/. [Accessed 10 January 2023].

10. G. Shahgholian, "A brief review on microgrids: Operation, applications, modeling, and control," Wiley Online Library, vol. 31, no. 6, 2023.

11. K. P. S. N. V. Bramareswara Rao, "A Review on Schemes for Interconnecting Microgrids of Urban Buildings," Microelectronics, Electromagnetics and Telecommunications, pp. 431-438, 2020.

12. L. D. Raji AK, "Modeling and optimization of community microgrid components," Energy Procedia, vol. 156, p. 406–411, 2019.

13. Ø. P. H. R. Johannsen RM, "Hybrid photovoltaic and wind mini-grids in Kenya: techno-economic assessment and barriers to diffusion," Energy for Sustainable Development, Vols. 1221-1240, p. 54, 2020.
14. N. P. Palanichamy C, "Micro grid for All India Institute of Medical Sciences, Madurai.," Clean Energy, vol. 5, p. 254–272, 2021.
15. S. S. Garg VK, "Techno-economic design and evaluation of a small community-based microgrid.," in Proceedings of Integrated Intelligence Enable Networks and Computing. Algorithms for Intelligent Systems. Singapore, 2021.
16. D. S. Boddapati V, "Optimal design and techno-economic analysis of a microgrid for community load applications," Advances in Clean Energy Technologies, pp. 456-466, 2021.
17. H. S. A. S. Mahmud DM, "Techno economic feasibility analysis of grid-connected microgrid," in 2021 IEEE 9th Region 10 Humanitarian Technology Conference (R10-HTC), Bengaluru, India, 2021.
18. R. R. A. S. R. Z. Shezan SA, "Design and implementation of an islanded hybrid microgrid system for a large resort center for Penang Island with the proper application of excess energy.," Environmental Progress & Sustainable Energy, vol. 40, pp. 13584-13596, 2020.
19. Microgrid software by HOMER Energy, [Online]. Available: https://www.homerenergy.com/.
20. J. D. D. Niyonteze, F. Zou, G. Asemota, S. Bimenyimana and G. Shyirambere, "Key technology development needs and applicability analysis of renewableenergy hybrid technologies in off-grid areas for the Rwanda power sector," Heliyon, 2020.
21. D. M. Mahmud, S. M. M. Ahmed, S. Hasan and M. Zeyad, "Grid-connected microgrid: design and feasibility analysis for a local community in Bangladesh," Clean Energy, vol. 6, pp. 447-459, 2022.
22. N. Saqib, K. Foysal Haque, R. Zabin and S. N. Preonto, "Analysis of Grid Integrated PV System as Home RES with Net Metering Scheme," in International Conference on Robotics,Electrical and Signal Processing Techniques (ICREST), 2019.
23. M. U. Khan , M. Hassan, M. H. Nawaz, A. Mazhar and R. Wazir, "Techno-economic Analysis of PV/Wind/Biomass/Biogas Hybrid System for Remote Area Electrification of Southern Punjab (Multan), Pakistan using HOMER Pro," in International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), Islamabad, Pakistan, 2018.

24. BERC, "BERC Electricity Tariff Order (Retail)," [Online]. Available: http://www.berc.org.bd/site/notices/999da7ce-b204-4bcc-987c-49678efa9983/BERC-Electricity-Tariff-Order-Retail-.

25 Riayatsyah, T. M. I., Geumpana, T. A., Fattah, I. R., Rizal, S., & Mahlia, T. I. (2022). Techno-Economic Analysis and Optimisation of Campus Grid-Connected Hybrid Renewable Energy System Using HOMER Grid. Sustainability, 14(13), 7735.